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Proceedings of the Sixth NMFS National Stock Assessment Workshop

Incorporating Ecosystem Considerations into Stock Assessments and Management Advice

What are the pros and cons of going beyond single species?

Hosted by the Northwest Fisheries Science Center
March 28–30, 2000, Seattle, Washington

Prepared by the National Marine Fisheries Service
Edited by Pamela M. Mace

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
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WELCOME

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I welcome all of you to Seattle for the 6th NMFS National Stock Assessment Workshop. These workshops allow NMFS experts to exchange information about their work and forge new collaborations. While we all are good at presenting our research at external conferences, we usually do not get many opportunities to discuss our research internally within our own agency. We all owe thanks to Mike Sissenwine for initiating these workshops six years ago when he was the NMFS Chief Scientist and to Bill Fox for expanding the theme of the workshops.

I am extremely pleased to host the 6th NMFS National Stock Assessment Workshop. It is particularly relevant that the NWFSC host this year's workshop with its ecosystem theme. As you know, our Center focuses on living marine resources of the Pacific Northwest: marine and anadromous fishes and their habitats. A major goal of our research programs is to incorporate the ecosystem principles and considerations that you will be exploring here over the next three days.

What do we mean by "ecosystem approach?" In simple terms, an ecosystem approach recognizes that plant and animal communities are interdependent and interact with their physical environment. To ultimately sustain our living marine resources and achieve optimum yield, fisheries managers must use a paradigm that recognizes and incorporates these ecological linkages among species and their habitats. Hence, our goal as scientists is to improve our scientific understanding of key aspects of the life histories of exploited species in a holistic ecosystem environment. In other words, we must examine the quality and health of the individuals; the relevant biotic interactions; and how these factors interact in relation to the physical environment that surrounds them. Only then can we fully understand variability in recruitment, stock structure, and the other components that collectively determine the condition of our fisheries.

Two broad areas of research focus at the NWFSC are centered on Pacific salmon and west coast groundfish. We are facing problems of declining stocks of both salmon and groundfish. Understanding of anthropogenic factors affecting survival and abundance of these stocks as well as long-term climate shifts and ecosystem factors, such as predation and prey resources, must be better understood in order to provide accurate forecasts of the potential for recovery of listed stocks, to help us rebuild overfished stocks, and to help us support sustainable fisheries.

As you all know well, large numbers of Pacific salmon stocks are listed as endangered or threatened under the Endangered Species Act (ESA). Our challenge is to provide strong scientific underpinning for recovery of Pacific salmon which have a complex life history. Our salmon analysis clearly embraces an ecosystem approach. Ecosystem studies include investigation of nutrient cycling from marine environment to freshwater habitats, and

elucidation of the biological and physical factors that affect survival of juveniles in estuaries and the coastal ocean. We have tied these research initiatives and analyses of risk together in a new approach that we call the "Cumulative Risk Initiative" (CRI). The CRI quantitatively examines the whole life cycle of salmon and all the factors that cause mortality and impede recovery. We consider genetics, habitat, harvest, hydropower, climate, and other factors (such as water quality) in order to understand the cumulative impact of natural and anthropogenic risk factors on salmon. One of our papers on Thursday will present this CRI approach which we see as a prototype for modeling other complex systems. We will be seeking to incorporate such cross-cutting ecosystem approaches into even more of our fisheries research.

For groundfish, we are involved with rebuilding overfished stocks on the west coast and evaluating the status of marine species, particularly seven species in Puget Sound which have been petitioned for listing under ESA. The high degree of urbanization in Puget Sound represents a major challenge because it layers human-caused factors over natural variability. Compared to the other four Science Centers, our groundfish program is relatively new. But over the past five years we have made major strides in building a groundfish program to improve our groundfish assessments, and developing new working relationships with diverse constituents. With collaboration of other west coast Science Centers, we are just now completing a comprehensive research plan for the west coast groundfish which spans topics from stock assessments to habitat to economics. We will be using this plan to prioritize our work in critical areas, while incorporating ecosystem principles in our assessments of groundfish.

The NWFSC has a long history of research on the effects of contaminants on marine species. Today, we are also working on the far-reaching principles of defining essential fish habitat for salmon and groundfish, and investigating Harmful Algal Blooms whose effects may spread broadly in an ecosystem.

Ecosystem principles must be embraced by the agency if we are to be stewards of living marine resources for the long-term. The challenge is "How?" Will single species assessments suffice in some situations? Can the high information demands of a full ecosystem model be met? Can we design safe, low information approaches that still allow sustainable fisheries for key species? This NSAW provides a great opportunity for scientists throughout NMFS to gather and discuss these issues.

We look forward to sharing our ideas and work with you this week, and learning from your ecosystem and stock assessment efforts in other areas.

INTRODUCTION

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The National Marine Fisheries Service (NMFS) National Stock Assessment Workshops (NSAWs) have two primary general objectives:

(i) to address an important and topical theme of common concern to all NMFS Science Centers
(ii) to provide a forum for interaction for a large diversity of NMFS scientists involved in conducting stock assessments, providing management advice, and related activities

Topics, host Science Centers and dates for the previous five NSAWs follow:

1ST NSAW: "Determination of Allowable Biological Catches", Southeast Fisheries Science Center, Miami FL, 19-22 March 1991.

2ND NSAW: "Defining Overfishing -- Defining Stock Rebuilding", Southwest Fisheries Science Center, La Jolla CA, 31 March - 2 April 1992.

3RD NSAW: "Bycatch and Discard Mortality: Sampling, Estimation and Implications for Scientific Advice", Northeast Fisheries Science Center, Woods Hole MA, 20-22 July 1993.

4TH NSAW: "Spatial Patterns: Survey Design, Geographic Analysis, and Migration Models", Alaska Fisheries Science Center, Seattle WA, 10-12 August 1994.

5TH NSAW: "Providing Scientific Advice to Implement the Precautionary Approach Under the Magnuson-Stevens Fishery Conservation and Management Act", Southeast Fisheries Science Center, Key Largo FL, 24-26 February 1998.

The theme for this, the 6TH NSAW, hosted by the Northwest Fisheries Science Center on 28-30 March 2000, was "Incorporating ecosystem considerations into stock assessments and management advice." This theme was chosen because it is highly topical and has wide appeal. While there has been a longstanding requirement in the Magnuson Act to incorporate ecosystem considerations in the fisheries management process, in most cases to date this has only been accomplished in a cursory or qualitative manner, and there is currently escalating pressure from scientists, fishers, managers, and environmentalists to more explicitly consider multispecies interactions and other ecosystem effects. In addition, two major committees have recently been working on ecosystem management in marine fisheries: one convened by the Ocean Studies Board of the National Research Council, which released its report on "Sustaining Marine Fisheries" in October, 1998; and an Ecosystem Principles Advisory Panel (EPAP) convened by the National Marine Fisheries Service, as required by the 1996 Sustainable Fisheries Act, which submitted its report to the U.S. Congress in April 1999. There have also been several recent conferences and symposia on ecosystem considerations (e.g., the 16th Lowell Wakefield Fisheries Symposium held in Anchorage AK in

October 1998 had the theme of "Ecosystem Considerations in Fisheries Management").

The theme of ecosystem considerations has potentially wide appeal to a large diversity of NMFS and other scientists and managers, including those involved in survey design and planning (who may need to redesign surveys to monitor whole ecosystems rather than just targeting particular species), stock assessment scientists (who may need to include multispecies or oceanographic effects in their assessment models and management advice, either qualitatively or quantitatively), oceanographers (who may need to develop or further expand data collection programs and models that explicitly incorporate physical or other oceanographic phenomena into assessment models), fisheries managers (who may need to weigh risks and benefits in a multispecies rather than a single species context), economists and other social scientists (who may need to develop models for evaluating trade-offs between different types of ecosystem perturbation in terms of net economic benefits), aquaculturists (who may need to evaluate the impacts of marine aquaculture on natural ecosystems), and virtually every other sub-discipline associated with fisheries.

A Steering Committee consisting of one representative from the headquarters Office of Science and Technology and one or two representatives from each of the Science Centers was formed to further develop the overall theme and organize the workshop. Steering Committee members were Pamela Mace (Office of Science and Technology), Ed Casillas (Northwest Fisheries Science Center, Rick Methot (Northwest Fisheries Science Center), Alec MacCall (Southwest Fisheries Science Center), Bill Overholtz (Northeast Fisheries Science Center), Mike Prager (Southeast Fisheries Science Center), and Grant Thompson (Alaska Fisheries Science Center).

The workshop consisted of seminars, poster sessions, software demonstrations, and discussion groups that addressed theme areas and formulated conclusions and recommendations pertaining to these themes. The four theme areas were

1. Ecosystem properties
2. Biological and technological interactions
3. Short and long-term climate and other environmental/oceanographic effects
4. Secondary effects of fisheries

The overall trigger question for the meeting was "What are the pros and cons of going beyond single species?"

This Technical Memorandum contains the Proceedings of the 6TH NSAW, including the full text of an overview paper presented by Jason Link of the Northeast Fisheries Science Center, abstracts of seminars and posters presented during the NSAW, discussion group reports, and a summary of workshop conclusions and recommendations on ecosystem considerations in stock assessments and management advice. The agenda is reproduced in Appendix I and a list of the 83 participants and their affiliations is contained in Appendix II.

OVERVIEW PAPER

Fisheries Management in An Ecosystem Context: What Does this Mean, What Do We Want, and Can We Do It?

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There has been considerable recent interest in ecosystem-based fisheries management, as evinced by several reports, books, and conferences (e.g., Christensen *et al.* 1996, Larkin 1996, the NRC Ocean Studies Board Meeting in Monterey, California in 1996 (ESA 1998), Jennings and Kaiser 1998, the Wakefield Symposium in Anchorage, Alaska in 1998 (Alaska Sea Grant 1999), the report of the Ecosystem Principles Advisory Panel (EPAP) 1999, Hall 1999, NRC 1999, the ICES-SCOR Symposium in Montpelier, France in 1999 (ICES 2000), and Kaiser and de Groot 2000). Several factors have contributed to the current relevance and awareness of this issue, including conflicts between stakeholders, disparate legislation, debate over the most important processes in an ecosystem, limitations of single-species management, and use of this perspective as a scapegoat to justify any position. It is insightful to remember that consideration of factors that impact marine resource populations in a context beyond just the species level has a long and notable history in fisheries science. Spencer Baird, in his seminal report to the United States Congress (1873), noted five areas of research needed to explore potential causes of decline in Southern New England fisheries:

"1. The decrease or disappearance of the food upon which the fish subsist, necessitating their departure to other localities.
2. A change of location, either entirely capricious or induced by the necessity of looking for food elsewhere, as just referred to.
3. Epidemic diseases, or peculiar atmospheric agencies, such as heat, cold, etc.
4. Destruction by other fishes.
5. The agency of man; this being manifested either in the pollution of the water by the discharge into it of the refuse of manufactories, etc. or by excessive overfishing, or the use of improper apparatus."

Certainly these are resonant of contemporary terms such as trophic cascades, regime shifts, essential fish habitat, top-down/bottom-up controls, and overfishing. There has been notable advancement of technologies, methodologies, and theory over the past 130 years to address these topics. Yet despite the attention given to this problem during the past century and a half, many basic questions remain unaddressed.

There are two major reasons why these questions have not been fully addressed. First is the inherent difficulty of ever fully elucidating, particularly to the point of predictability, the multiple and complex dynamics of ecosystems. Second is the lack of unambiguous terminology used to identify the issues in an inter-disciplinary context, especially given the ecological, oceanographic, ichthyological, social, and economic mosaic within which fisheries management operates.

So let us start by asking what does the term

"ecosystem" mean? This term likely evokes thoughts of multispecies approaches or the entire fish community for many fishery scientists, but is actually much broader than this, including the entire food web and all abiotic factors that act upon a system. An ecosystem is defined as "an ecological community together with its environment, considered as a unit" (adapted from Tansley 1935). Ecosystems are complex, and cover many processes at many levels of the biological hierarchy. Once one takes a complex system and attempts to assess it in an even more complex socio-political arena, many ambiguous terms become associated with the topic of ecosystem management. Let us attempt to clarify these terms.

Are we really doing ecosystem management in a fisheries context or fisheries management in an ecosystem context? I submit the latter. Technically, we cannot manage an ecosystem. Ecosystem-based fishery management is effectively shorthand for more holistic approaches to resource allocation and management (Larkin 1996). The question then becomes, what are we trying to do with ecosystem-based fishery management? Are we trying to simultaneously optimize total fish yield in a system, optimize the yield of a particular species, provide long-term economic viability, conserve biodiversity, maintain a particular ecosystem state, protect certain species, or protect certain ecosystem services? It is clear from this list of objectives that there will be conflicting goals. The Ecosystem Principles Advisory Panel (EPAP 1999) report to the United States Congress simply states that the goal of ecosystem-based fisheries management is to maintain ecosystem health and sustainability.

Ecosystem health is a misnomer. The human analogy of medical homeostasis or toxicological resistance does not apply (Wicklum and Davies 1995). If humans have a blood pressure, pulse rate, temperature, and brain wave activity within a certain range, we are healthy. If these and related metrics are outside of a specified range, we are termed unhealthy and if we persist outside of this range we will ultimately cease to function. Alternatively, ecosystems can exhibit multiple states that are just as functional as any other. Some states are certainly more desirable than others, but many are viable. I propose we use the term "ecosystem status" instead of ecosystem health to describe the condition of an ecosystem in a less subjective and value-laden manner.

Ecosystem products (or services) is a term that connotes the measurement and evaluation of specified outputs produced by a system. Although a useful term, we should remember that there are services provided by an ecosystem beyond the scope of fisheries management. For example, marine ecosystems provide the basis for tourism, ecotourism, diving, transportation, climate regulation, CO_2 scrubbing, mineral extraction (oil and otherwise), discovery of new materials, and development of new medicines, in addition to commercial and recreational fishing. How we collectively prioritize these products, maintain the ability of a system to continue to produce these services, and recognize the impacts of fishing on these aspects of the ecosystem remains a key challenge for national and international resource management.

Ecosystem integrity is also a subjective term. How do we measure, reproduce, or evaluate integrity? This implies that unless we do something, whatever that may be, the critical processes in an ecosystem will break and cease to function. As discussed earlier, ecosystems will continue to function, albeit with different configurations. I propose we use the term "ecosystem sustainability" instead of ecosystem integrity to refer to the maintenance of specified processes we would like to see persist in a system. We can measure and evaluate processes in a system over time to ascertain how sustainable a particular ecosystem state might be. However, this begs the question, what is it that we are attempting to sustain?

There is a duality when considering ecosystem approaches to fisheries management. The argument has polarized about two extremes: either one can approach management from the perspective of the entire ecosystem, or from a single-species approach that is cognizant of broader ecosystem considerations. Single-species approaches generally do not consider species interactions, changes in ecosystem

structure or function, biodiversity, non-fishing ecosystem services, protected or rare species, non-target species, ecosystem effects of discarding unwanted bycatch, or gear impacts on habitat. Conversely, ecosystem approaches generally do not consider demographic parameters, density-dependent effects, stock-recruitment relationships, genetic diversity, economic tradeoffs, or standards, reference points and performance statistics. This duality is really a false dichotomy, and actually represents two extremes along a gradient (Figure 1). We can and should incorporate some of the best aspects of all approaches from this gradient.

This gradient of approaches implies several opportunities and tradeoffs. We can maintain a single-species approach and forget ecosystem issues, conduct multiple single-species assessments in "harmony," conduct single-species assessments with explicit predation mortality or habitat or climate considerations, conduct multispecies assessments, construct aggregate biomass models, or drop population dynamics entirely and focus on whole system models. Certainly more methodology is available at the single-species end of the spectrum and this is much cheaper (in terms of dollars, time, and data) than the ecosystem end of possible approaches. Conversely, the higher end of the hierarchy incorporates a greater variety of processes more explicitly and captures many critical factors that are omitted from the single-species approaches. Regardless of our current position along this gradient, it is clear that we will have to incorporate a broader, more interdisciplinary approach to fisheries science.

One explicit consideration should be biomass tradeoffs. We know that the sum of single-species MSY is greater than MSY for the system, and it is energetically impossible to simultaneously maximize yield for multiple species. Our objective, as difficult as it may be, should be to specify the species mix we want in the fish assemblage of an ecosystem, which raises the consideration about alternative steady states. Presuming we can even agree what the optimal ecosystem state should look like in terms of species composition, relative abundance, and other factors, it is questionable if we can manipulate a system to that end. Although we may desire to go back to the "glory days" of a certain ecosystem state, we need to be frank about the probability that a multispecies trajectory may not be reversible, particularly given environmental regime shifts and habitat changes.

This brings us to what is doable and what is intractable. I do not mean to imply that the task of ecosystem-based fisheries management is hopeless, when in fact we can set up bounds that may increase the chances of sustaining a certain fish assemblage that concurrently minimizes ecological impacts to a system. How do we implement such considerations into fisheries management? In many instances, we already do. There are several FMPs that consider groups of fish as assemblages, there are ecological considerations written into many of the same FMPs, there are many single-species assessments that incorporate a host of broader considerations, and there are several multispecies or aggregate models that exist and have been used with some success. Let us continue to use and expand upon these approaches.

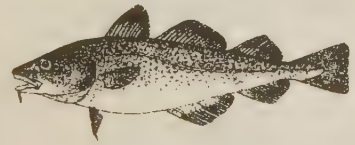
What do we need to do to improve our implementation of ecosystem considerations in fisheries management? First, we need to continue the dialogue to clearly define our goals in an ecosystem context, and develop protocols to resolve competing goals for any given ecosystem. This will be an iterative process, and we will want to ensure that all stakeholders are provided an opportunity for input. Second, we should explore a suite of ecosystem metrics and indicators to determine if there are ecosystem analogs to single-species reference points, standards, and control rules. Table 1 lists examples of indices, parameters, and similar metrics along the gradient that may be useful to determine whether an ecosystem is overfished. We should ask if these metrics are general enough to be useful, sensitive to change, feasible to measure, and incorporate uncertainty. Third, we need to develop and apply more appropriate theory, models, and methods at the aggregate and system level. Some of these approaches exist or can be extended from single-species approaches, but several associated issues have yet to be fully explored. This is a fruitful area for research. Fourth, we should maintain current

Can Control & Measure Fishing Effort — Realism

Parsimony — Addresses Ecosystem Issues

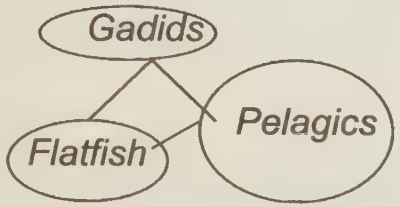
Existing Methods and Metrics — Data Requirements (=Cost)

Stock/Single Species



Multi-species

Aggregate Biomass



Ecosystem

Messy Picture Here

Predation, Competition, Mutualism, etc.

Habitat, Climate, etc.

Disease, Genetic Diversity, Fecundity, Migration, etc.

Technical Interactions

Figure 1. A gradient of possibilities from single-species to whole system approaches for fisheries management, noting key processes and pros or cons at each level.

monitoring and establish additional monitoring programs. Maintaining current monitoring is essential to provide baseline information for key species and many of the system-level emergent properties can be calculated from our extant resource survey data. Expansion of monitoring programs is essential to include habitat characterization, environmental variables, and non-target species. Finally, we need to formalize Fishery-Ecosystem Plans (FEPs). What should an FEP look like? We need to review these issues and develop guidelines similar to, but qualitatively different than, those that exist for single-species FMPs.

What does an ecosystem approach to fisheries management provide that we cannot obtain from a single-species approach? An ecosystem approach more explicitly addresses the effects of fishing on non-target species, on habitat, on species interactions, and on whole system processes. This approach explicitly recognizes that marine ecosystems provide other "goods and services" besides fishery harvest; it addresses biomass tradeoffs among species; and it provides increased accountability from stakeholders. This approach changes the burden of proof to a more precautionary perspective.

Table 1. Examples of ecosystem emergent properties that can be measured and perhaps serve as proxies for decision criteria in fisheries management.

Systems Analysis (Cybernetic) Metrics	Exergy, emergy, total production, total biomass, energy flux, resilience, persistence, resistance, stability, free energy, information content
Aggregate Metrics	Mass flux, ascendancy, redundancy, developmental capacity, guild composition, trophic transfer efficiency, production and biomass in a trophic level or group
Food Web Metrics	Connectivity, trophic links, modal chain length, % omnivory, % cannibalism, linkage density, allocation of species across trophic levels, interaction strength, cycles, predator/prey ratio
Community Metrics	Diversity indices, size spectra, species richness, evenness, dominance, overlap indices, interaction indices
Single-species Metrics	MSY, F_{MAX}, F_{MSY}, $F_{0.1}$, $F_{20\%}$, SSB, MEY, F=M, Z

Conclusions

Fisheries management in an ecosystem context is feasible. Yet it will not work without clearly defined goals. Several metrics exist that can measure ecosystem status independent of particular goals. We should explore these indicators as the goal-setting process continues.

Ecosystem considerations do not substitute for what we already know from a single-species approach. We still need to reduce fishing mortality and fishing capacity. We still need to continue monitoring. Invoking ecosystem considerations is

not a crutch for failing to implement clear-cut single-species fisheries management advice.

Ecosystem approaches augment single-species approaches and provide complementary information that one cannot obtain from classical methods. As more and more stakeholders become involved with fisheries issues, we need to be as inclusive as feasible. Recognizing the complexity of ecosystems will change the burden of proof.

As we continue to develop ecosystem-based fishery management, several questions need to be kept in mind:

1. Why bother with this approach?

   What does this tell us that we couldn't get from a single-species perspective?

2. What are the goals of fishery management in an ecosystem context?

   Are they clear? Are they realistic? Are they feasible?

3. What is the best approach to use along the gradient?

   How much data will it need, and is this available or feasible to obtain? What are the pros and cons of each approach? What are the costs?

4. Are there ecosystem analogs to single-species overfishing definitions?

   How do we know if an entire ecosystem has been overfished, particularly relative to other edaphic perturbations? Can we set decision criteria? Can we agree on a certain ecosystem configuration? Can we manage it to that end?

5. How do we implement ecosystem-based advice?

   What should be included in a Fishery Ecosystem Plan? How do we educate others about these issues? Do we need a paradigm shift and if so, will this approach enable one in the current management culture?

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ABSTRACTS OF PAPERS & POSTERS

Carrying Capacity of Apex Predators and the Frequency and Cadence of Physical Forcing in Marine Food Webs

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Carrying capacity has been defined as the maximum biomass "supportable" for a given level of primary productivity. For apex predators, this supportable biomass is also a function of food web structure. Current discussions emphasize that carrying capacity may change as part of a "regime shift." In this frame of reference, a shift in primary productivity may be considered to be an alternation between two carrying capacities. However, if the change represents an oscillation, changes in the food web structure or an apex predator's long-term carrying capacity will depend not only on the amplitude of the oscillation, but on its frequency and cadence, where cadence is defined as the sequencing of the extremes of productivity.

In this paper, we examine quantitative models of several North Pacific marine food webs. The ecosystems range from the Bering Sea to subarctic and subtropical gyres to the eastern tropical Pacific. Each ecosystem has been hypothesized to respond differently to El Nino Southern Oscillation (ENSO) and decadal scales of physical variation. For each model, we determine a "static" carrying capacity for apex predators, or the biomass supportable if primary productivity remained constant. Then, we manipulate each system by varying the frequency and amplitude of primary production to ask "on what scale of variation does each ecosystem maximize production?" The results are compared to changes in frequency, amplitude and cadence of forcing that may be expected under scenarios of long-term climate change, and under fishing pressure which may not have evolved to take advantage of the natural variation within the system.

Straying from the Eco Path

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Ecosystem modeling and managing must explicitly examine predator/prey interactions, and the software packages ECOPATH and ECOSIM have achieved prominence as a possible approach to such modeling. The models are extremely general, and this generalization is both their weakness and their strength. In particular, the generalizations allow researchers to compare energy flow between ecosystems, while the relatively small parameter set allows modelers examining a single ecosystem to compare different types of single-species models for internal biological consistency.

Moreover, while ECOPATH and ECOSIM cannot yet make explicit predictions for specific stocks, they may be extremely good tools for examining changes in natural mortality and predator/prey interactions which may occur across environmental regime shifts, and affect the assessment of fished stocks.

So what use is a mass balance (*not* equilibrium!) food web, and what tricks can it perform? Our aim is to introduce the use of ECOPATH and ECOSIM with a healthy sense of skepticism that must accompany any model, and determine what ECOPATH can and cannot do in terms of marine ecosystem management.

Effect of Nutrient Cycling from Carcasses on Salmon Productivity

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Research over the last decade has established the ecological importance of the contribution of nutrients and organic matter that spawning Pacific salmon make to the freshwater habitats where they spawn. A large proportion of the nitrogen in plants and animals in streams where salmon are abundant may be derived from spawning fish and juvenile salmonids exhibit higher growth rates at locations where carcasses are available. No method of establishing salmon escapement goals that meet the nutritional needs of streams is available. We examined the relationship between abundance of spawning salmon and the nitrogen stable isotope ratio of coho salmon parr to determine whether a saturation level for salmon-derived nitrogen could be identified. Coho parr were collected from 26 sites in western Washington in late winter. The isotope ratio in the coho parr was related to the abundance of salmon spawning at that site the previous autumn. The amount of carcass-derived nitrogen increased with increasing abundance of carcass tissue up to 0.15 kg of carcass/ m^2 of streambed area but exhibited no increase above this level. These preliminary data suggest that relationships between stable isotope values and carcass abundance may provide a useful supplement to traditional methods of establishing escapement goals for Pacific salmon.

Simulated Fishery and Trophic Impacts of Tuna Fisheries Compared with Direct Fishery Impacts on Single Species

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We constructed an Ecosim (http://www.fisheries.com) model of food web and fishery interactions for the Central North Pacific using known trophic relationships, estimates of mortality rates, harvests of commercially important species, and estimates of exploitation rates and biomass for target tuna species in the 1990's. Most other harvested species (e.g., sharks and billfishes) were assumed to be almost fully exploited. The model included commercially important species, as well as bycatch and forage species for which mortality rates were guessed.

We then used the model to simulate a gradual reduction in exploitation rates, following a reversed trajectory of the industrial-scale expansion of longline, pole-and line, troll, purse-seine, and high-seas drift net fisheries since the late 1940's. The Ecosim model predicted a much greater abundance of sharks, marlins, broadbill swordfish, and large tunas prior to the industrial-scale fishery. In contrast, mahimahi and several smaller species were less abundant than recently observed.

To better understand the model output, we separated biomass changes attributable to fishing mortality from those due to changes in prey abundance or predation. This analysis suggested that indirect effects of fishing (i.e., trophic effects) contributed both to the current low abundance of slower growing groups such as sharks and marlins, and to the increased abundance of faster growing species. As exploitation increased across the Pacific, species like mahimahi may have become more abundant as their less productive competitors and predators (tunas, billfishes, and sharks) became less abundant. The current food web configuration is a product of both the direct effects of fisheries-induced mortality and the indirect effects of species interactions that are altered by exploitation.

In another model run, we simulated recent increases in pelagic shark mortality rates due to the increased marketability of shark fins. The simulated shark populations were very sensitive to overexploitation. However, declines in shark populations had little impact on the food web. This unexpected results contradicted a popular idea that pelagic sharks must be "keystone predators" which have a stabilizing influence on food web diversity and biomass. The simulation was repeated with the diet of sharks exaggerated towards greater selectivity for other large predators at the top of the food chain. With the diets altered in this manner the simulations did produce perceivable effects on food web structure.

Ecosystem Management: How Can We Do It?

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The ultimate goal of an ecosystem approach to management is sustainability of marine ecosystems. Imagine a scenario with diverse biota, stable yields, mature fish thriving and spawning, profitable industries, reliable seafood products, ample recreational fishing and tourism opportunities, and low-impact fishing practices - the veritable bounty of the sea! But how do we achieve such lofty goals? Precisely what do we want to sustain?

We assert that to address these goals, they need to be translated into quantifiable terms; i.e., metrics. Biotic metrics range from single-species to whole-system attributes. Abiotic metrics describe environmental conditions. Human metrics (e.g., fishery capitalization, profitability, recreational fishing opportunities, pollution, and regulatory compliance) are essential for grounding policy discourse in the face of differing value systems. Directionality, sensitivity, generality, feasibility, and uncertainty are key factors when selecting metrics. We present several metrics ranging from single-species to whole-system measures and discuss criteria for their usefulness and implementation.

We assert that a full suite of metrics should be examined to account for diverse system properties; e.g., spawner abundance, fishery capitalization, habitat quality, biodiversity, bycatch, primary production, or performance of regulations. These metrics serve as the basis for decision criteria and reference points for the management process. One of our most recurrent observations is that human behavior is the key factor to manage in an ecosystem. We submit that a suite of metrics can help to identify win-win situations much more clearly than a single-species approach.

We examine some fisheries where metrics have been successfully used. While it is clear that tangible goals, multiple metrics, and adaptive management are needed to sustain ecosystem properties, it is also clear that the practice of ecosystem management is just beginning.

Estimates of Bycatch by the U.S. Atlantic Pelagic Longline Fleet during 1993-1998

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Estimates of the bycatch from U.S. Atlantic pelagic longline sets targeting tuna or Atlantic swordfish are presented. Bycatch in this instance refers to all animals which were discarded at sea, whether alive or dead at the time of release. The estimates were based on bycatch rates from a randomly selected sample of the fleet recorded by scientific observers, and fishing effort reported in mandatory logbooks from sets targeting tuna or swordfish. Bycatch rates reported in the mandatory logbooks were not used for the estimation, although some comparisons are made between estimates and reported levels. The estimates were calculated by year, quarter and area (Gulf of Mexico, Caribbean, Southeast Coastal, Northeast Coastal, Southeast Offshore, and Northeast Offshore). The estimates were constructed using a delta- lognormal method in which the bycatch for a particular species within each stratum is a function of 1) the proportion of the sets on which discards of the species were observed, 2) the discards per hook rate observed (assuming a lognormal distribution), and 3) the number of hooks reported set. For cases in which the observed sample sizes were low, the proportion of positive sets and the bycatch rate were calculated by pooling across years (the strata determined to be least significant according to General Linear Model analysis) and, if necessary, across years and quarters to achieve designated minimum sample sizes. Results are presented for two minimum sample size levels: 5 and 30 observed sets. Confidence intervals (95% CI) are also calculated. Unlike existing alternative methods for bycatch estimation, estimates and confidence intervals can be quickly and easily calculated for all species with longline interactions, without the use of self-reported bycatch rates.

Using the bycatch estimation methodology to estimate landed catch generally produced similar values to the landings reported in the logbooks and in the existing commercial landings reporting system. However, estimates of bycatch tended to be substantially higher than the levels reported in the logbooks. There were also significant differences in the live/dead ratio of discarded catch between the observer data and the logbooks.

Associations of Species Groups from U.S. Pelagic Longline Sets in the Region of the Grand Banks with Gear Characteristics and Environmental Variables

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Although the primary target of U.S. longliners fishing in the Grand Banks is swordfish, blue sharks are the most frequently caught species in this region. Blue sharks and other bycatch species are an issue for this fishery. The purpose of this study was to investigate relationships between the gear characteristics, environmental variables, and catch composition. Cluster analysis was used to group targeted and non-targeted species that tend to be caught on the same set and to identify differences in gear variables (depth of fishing, mainline length, percentage of light sticks per hook set, soak time, and set speed) and environmental variables (temperature, month, and hour of set) on species composition. Swordfish catch was separated into large ($\geq$ 41 lbs. dressed weight) and small swordfish ($<$ 41 lbs. dressed weight) because most swordfish under 41 lbs. are regulatory discards.

The data were grouped into five clusters: swordfish, mixed (swordfish and tuna), tuna, summer blue shark, and fall blue shark. Hour of set, soak time and set speed were relatively neutral in the analysis. In the case of hour of set, the analysis was inconclusive since the expected difference, based on earlier studies, was between sets starting before or after 9 PM. However, only 6 of the sets in the data file were started after 9 PM. Depth of fishing, mainline length, percentage of light sticks per hook set, temperature at the beginning of set, and temperature at the beginning of haul varied between clusters and were further investigated in plots with species groups.

Temperature variations between clusters were associated with seasons. Within the blue shark clusters, interactions were found between temperature, month and blue shark catch. Within the non-blue shark clusters, catch of undersized swordfish and turtles tended to increase as temperature increased. Blue shark clusters had shorter longlines than the swordfish cluster. Catch of undersized swordfish increased with increasing mainline length and with the percentage of light sticks set. Turtle catch decreased as the depth of fishing increased.

An Economic Analysis of Quota Induced Discarding

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A common fishery management tool for reducing the fishing mortality of a particular species is to impose a harvest quota. However, in multispecies fisheries, quotas have been criticized for only affecting dockside landings and marketing of the restricted species, but not necessarily its catch. That is, fishermen have found that they can comply with the quota and at the same time continue to catch the restricted species along with other, marketable species by simply discarding the restricted species at sea, a practice that can result in up to 100% mortality.

This paper presents an ex ante analysis of the effectiveness of quotas for achieving resource goals from an economic perspective. In particular, the approach adopted uses the concept of virtual prices to model the effects of rationing harvest on multiproduct, profit maximizing firms. The first section identifies the scenarios under which a quota provides an adequate price incentive to achieve the intended result; i.e., the policy does not induce discarding.

To further ground this discussion, an empirical example using data from the multispecies pelagic longline fleet in Hawaii is provided. The short-run supply response model specified is based upon a restricted profit function that controls for both vessel and time-specific effects and is explicitly conditioned on stocks. Not surprisingly, results indicate that if the species is low-valued or is a small component of trip revenue, the quota has a negligible effect on harvest and discarding practices. Further, results indicate that even when the quota is on a high-valued species, substantial discarding can result depending on whether the species is a substantial portion of trip revenue.

A Conceptual Basis for Fishery Resource Portfolios

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Recent interest in ecosystem-based management is causing fisheries economists to reconsider their bioeconomic models and management advice. Single-species models imply separability that does not necessarily exist in nature or fisheries owing to ecological interactions, joint production technology, and consumers' willingness to substitute one species for another. Predation results in multiple single-species B_{MSY} - one for each level of the predator (prey) population. Fishing gears often do not catch species in proportion to B_{MSY}, and dockside prices cause fishermen to retain species in different proportions. Practical application of single-species management and its recent extension to essential fish habitat can lead to perverse economic outcomes whenever policy is driven by the "weakest" population. For example, scalloping inside groundfish closed areas in the Northeast Region is strictly limited by recovery plans for yellowtail flounder and the juvenile Atlantic cod Habitat Area of Critical Concern.

We are investigating whether portfolio theory offers a conceptual framework to integrate *aggregate* economic yield from interdependent species and fisheries. We maintain that fisheries *management* is an economic activity (versus a conservation activity) that should be constrained by requirements to maintain ecosystem functions and prevent extinctions. Beyond these restrictions, biomass tradeoffs and people's preferences for food, recreation, and livelihoods determine which species to manage and their desired biomass and harvest levels.

A fisheries portfolio is comprised of risk-bearing assets (fish stocks with stochastic recruitment) that yield dividends (harvest) over time. We assume that society is risk averse and prefers greater long run benefits to lesser expectations. To avoid "externalities," the composition of a portfolio is influenced by trophic interactions and joint production. Asset levels (biomass) and attributes (e.g., size structure) are selected and adjusted in order to maximize aggregate economic benefits, subject to risk preferences and constrained by energy in the system and the need to preserve trophic structure and a functional notion of biodiversity. In a sense, the current management matrix would be transposed from one that manages individual species throughout their range to one that manages the species complex of a fishing area, including its habitat.

An essential complement to our portfolio framework is the property rights perspective on ownership. Fish stocks that are exposed to non-exclusive (i.e., open access) exploitation are valued only for short-run dividends; they are not economic assets. Asset value requires ownership and effective enforcement. The general options are governments that are either sole owners or managers for the public, or mutual fund arrangements with shares owned by a multitude of individuals in a commons or corporation.

Trophic Dynamics Affect Salmon Productivity: Ecosystem-Wide Considerations

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Recent declines in ocean salmon survival, uncertainty in predicting adult salmon returns, and accurately quantifying the effectiveness of freshwater restoration efforts, highlight the need for marine ecosystem studies. While simple physical oceanographic measures sometime correlate with ocean survival of salmon, they have little explanatory power, and often persist for only short time-series. The Estuarine and Ocean Ecology Program is presently involved in multi-disciplinary studies to identify critical biotic interactions that influences juvenile salmon marine distribution, growth, feeding habits, predation, health, and survival off the Pacific Northwest. Changes in the Northwest marine ecosystem during the past decades have not contributed to healthy marine survival. Declines in zooplankton biomass and species composition and changes in predator and forage fish composition have affected salmon distributions and feeding habits, presumably affecting survival. Presently, our ability to predict salmonid marine survival is hampered by our incomplete understanding of critical bio/ physical interactions in the ecosystem. We believe that our research will eventually enable us to identify key biotic relationships, which if regularly and consistently monitored, will permit accurate salmonid productivity assessments.

Our present research focuses on distribution and abundance of salmon and other ecologically related species in the pelagic coastal zone. This habitat has not been adequately studied or sampled on a regular basis. Nevertheless, the Northwest pelagic coastal zone habitat is utilized by the early and full life history stages of many ecologically and commercially important fishes (e.g., salmon, rockfishes, sablefish, sardines, and anchovy) and invertebrates (Dungeness crab).

Variation in the intensity and strength of upwelling events, Davidson current, El Nino, and regime shifts occur at daily, annual, interannual, and decadal periods, respectively. Examining relationships between spring sea surface heights and upwelling anomalies highlights this variability. While these metrics were inversely related in the 1970s and early 1980s, they became uncoupled in the 1990s. During this period, salmon ocean survival declined markedly, with ocean survival of coho salmon in the Oregon Production Index area lowering to 1%.

We have observed large fluctuations in predator and forage fish species and prey resource composition in the Pacific Northwest, especially obvious since the early 1980s. For example, Pacific hake, mackerel, Pacific herring, and Pacific sardine have become abundant while market squid, eulachon, and northern anchovy abundance apparently declined. Similarly, zooplankton volumes in the California Current have declined since the early 1970s, while the copepod species community off Oregon changed in composition. Subarctic neritic copepods, which dominated the zooplankton community in the early 1970s in Oregon coastal waters, have declined in abundance, while California Current and subtropical

neritic species have increased.

Historical data analysis along with an ongoing integrated sampling program in the Northwest nearshore coastal region, which includes fish health, parasite, and disease measurements, will generate data which will be used to identify bio/physical mechanisms which affect salmonid and other marine species recruitment patterns. These data will be incorporated into realistic ecosystem models for the nearshore pelagic zone. These models should assist with Northwest fishery management in the near future.

MOVEFISH: a Spatial Algorithm for Simulating Movement of Billfishes

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During the development of a simulation model of recreational fishing for billfish (blue marlin and white marlin), *MOVEFISH,* a stochastic spatial algorithm, was developed to initially disperse a specified abundance of fish over a defined study area. The algorithm initially distributes the population randomly within the study area, with each fish assigned a position and random direction vector necessary to begin the simulated movement. At each time step, each fish is moved discretely from its current location to one of the adjacent locations based on a strategy having a probabilistic preference for movement towards areas of higher environmental quality which is considered to be reflective of the quality of the habitat.

Following some suitable number of time steps, the fish population is stochastically distributed with preferential directional movement towards areas of preferred habitat. The tendency for the simulated population to aggregate in higher than average densities is a function of the concentration parameter of the von Mises (Circular-Normal) Distribution used to drive the system. The appropriate number of time steps is determined based on an aggregation index that is a quantitative representation of the amount of clumping of the population under specified conditions.

The algorithm can be used both in a stand-alone fashion to explore distributional effects of various habitat hypotheses, and as the mechanism for fish movement in an overall simulation model of a fishing process where the position and final direction of movement for each fish becomes part of the initial conditions for beginning that overall simulation model.

This paper details *MOVEFISH* and presents results under one specified habitat preference within a defined study area.

Habitat Loss, Carrying Capacity, and Fishery Management

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The implications of habitat loss and degradation for the development of biological reference points and fishery management strategies has not been extensively explored. The need for a more holistic approach to management is now increasingly recognized and the development of approaches to account jointly for the direct and indirect effects of fishing practices is required. In this paper, the linkage between habitat and carrying capacity is explored in the context of simple production models. The implications of habitat loss (and reduction in carrying capacity) differ substantially in the development of biological reference points depending on whether the harvesting activity results in habitat degradation or whether habitat loss is caused by exogenous factors. For the case of exogenously driven changes in carrying capacity, the level of maximum sustainable yield changes monotonically with changes in carrying capacity but the level of fishing effort resulting in the maximum yield is not changed. In contrast, for the case where fishing simultaneously removes individuals and also results in declines in carrying capacity, the level of fishing effort resulting in maximum sustainable yield is lower (as is the level of maximum sustainable yield). The shape of the production function is also altered substantially. It is possible that harvesting practices will change both the carrying capacity of the environment and the intrinsic rate of increase. This again leads to conditions in which the optimal level of fishing effort is lower relative to the case where only the carrying capacity is affected by exogenous factors.

Relatively few studies are currently available on the implications of fishing practices for carrying capacity. In order to examine the issues posed above, directed studies are required. Experimental approaches to the problem are possible using marine protected areas and/or resource addition experiments. An explicitly experimental approach with replication will yield the quickest results. Accordingly, as new marine protected areas with no-take protection are defined, careful attention should be given to designing monitoring programs that will track changes in abundance and production with the reserve. Similarly, tracking the effects of habitat additions (e.g., deposition of shell for oyster reefs or planting submerged aquatic vegetation (SAV) beds) with respect to overall carrying capacity can yield important insights. Baseline studies prior to the implementation of the reserve or the addition of habitat should be an integral part of the overall strategy.

Alternatively, time series of changes in habitat and/or habitat quality could be related to changes in production. Methods for quantifying habitat are illustrated using areal surveys of SAV in shallow waters and the application of sidescan sonar. These techniques are also capable of detecting and quantifying fishing impacts on the habitat.

Measures of Overfishing Based on MSY

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We can't conduct management at the ecosystem level without also managing simultaneously at other levels: we cannot give up management at the level of the individual species and we have to include the biosphere. Furthermore, management at each level must be consistent with management at the other levels. This can be done by managing human enterprise to fall within empirically observed normal ranges of natural variation. For example, human influence can be guided by the limits observed in: 1) the ways other species interact with, and influence each other, 2) the ways other species interact with, and influence, ecosystems and 3) the ways other species interact with, and influence, the biosphere. Doing so avoids singular focus and over- (or under-) emphasis on factors being taken into account. Systemic management based on empirical information requires focus on each element of the spectrum of specific management questions while taking into account the suite of relevant factors in proportion to their relative importance. Thus, systemic management overcomes the inadequacies of conventional approaches. Among such approaches are those derived from the concept of maximum sustainable yield (MSY) for managing fisheries. Empirical information also allows for an appraisal of just how misleading conventional approaches have been.

Thus, overfishing can be measured through applying current management principles to demonstrate the problems of conventional management. The mortality rates caused by fishing on individual resource species has been on the order of 15 to 700-fold greater than the mean of predation rates on these same prey species by consumer species other than humans. There is a 20 to 300-fold greater consumption rate by fisheries harvesting groups of species, such as finfish in the Bering sea, compared to the mean of consumption from such groups by non-human species. Similar comparisons at the ecosystem level show that fishing is extracting biomass from various ecosystems at rates that are 20 to over 2000-fold more than the biomass that is consumed in these systems, on the average, by other consumer species. At the level of the entire marine environment, fisheries are harvesting biomass at rates that are almost four orders of magnitude larger than the biomass that is consumed by other species. The collective effects of fishing at these magnitudes have contributed to recent changes observed in marine ecosystems.

Marine Mammals: Examples of Sustainability

(poster)

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What do marine mammals have to do with fish and fisheries? Data for the consumption rates by marine mammals demonstrate how they are more than competitors: they serve as a source of important empirical information for the successful management of fisheries. Such information provides guidance for allocating harvests of fish over time, space and resource species - all with compatible objectives. Fisheries management based on such information would be consistent in its application to harvest strategies involving populations, individual species, groups of species, ecosystems and the entire marine environment. Such management would solve most of the existing problems associated with conventional approaches to fishery management.

Marine mammals have evolved within their complex environment, including all interactions with other species. Each species is defined by its own unique behavioral, morphological and metabolic characteristics. Each has a geographic distribution, density and population size. Many species of marine mammals consume fish or the prey of fish and therefore compete with fisheries either directly or indirectly. However, marine mammals also provide natural examples of sustainability: predation and fishing are analogous.

Consumption of biomass serves to illustrate this point. Examples of sustainability are provided by the consumption rates empirically observed for each individual species of marine mammal. Each species consumes particular prey species and has done so at rates that have persisted over evolutionary time scales. Like other features, these patterns of consumption show variability. The limits of this variation can be determined and help define what is sustainable. Sustainability is similarly defined by limits seen in the rates that marine mammals feed on groups of fish species, or consume from ecosystems, or from the marine environment as a whole.

This approach to fisheries management takes a systemic view of marine mammal-fisheries interactions. If adopted, it would solve most of the problems of managing fisheries in an ecosystem context.

Steller Sea Lion-Induced Changes in the Management of Pollock and Atka Mackerel Fisheries in the North Pacific, 1998-2000

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Groundfish fishery managers in the North Pacific Ocean have recently made changes to the fisheries for walleye pollock and Atka mackerel to decrease potential competitive interactions with the ESA-listed Steller sea lion. Changes consist of measures to partition fisheries from sea lions near rookeries and haulouts, to decrease the spatial concentration of the fishery in critical habitats of sea lions, and to disperse the fishery temporally. These actions were taken because of increased removals of pollock and Atka mackerel from sea lion critical habitats, and were intended to reduce the likelihood of fisheries-induced local depletions of sea lion prey and allow for sea lion recovery.

The effect of these actions on Steller sea lion prey availability, however, is largely unknown. Under the Endangered Species Act, the management agency is required to demonstrate that its proposed actions will not jeopardize the continued existence of a listed species nor adversely modify its critical habitat. In effect, this shifts the burden of proof from the species to the management agency. In this case, NMFS was unable to show that the fisheries would not jeopardize sea lions, which, in effect, drove the jeopardy determination (for the pollock fishery). Given the uncertainty in our understanding of fisheries impacts on sea lion prey availability, attempts to prove that the imposed changes are effective in mitigating jeopardy has been problematic.

Trophic Cascades and Intraguild Predation in Aquatic Food Webs

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Intraguild predation occurs where a consumer of a resource (the IG predator) is also a predator on another consumer (the IG prey) of that resource. Intraguild predation and its close relative cannibalism occur frequently in both marine and freshwater food webs. I investigated how intraguild predation and cannibalism affect top-down trophic cascade phenomena. In the absence of cannibalism among IG prey, an increase in the mortality of the IG predator will always lead to an increase in the competitively superior IG prey, and hence to a somewhat counterintuitive decrease in basal resource abundance. This effect can be neutralized or reversed by cannibalism among the IG prey. One important example of intraguild predation is when planktivorous fish consume both herbivorous and carnivorous zooplankton. I modeled systems which include compartments for phytoplankton, herbivorous zooplankton, carnivorous zooplankton, and planktivorous fish, and compared their properties to those of a tri-trophic food chain of fish, herbivorous zooplankton, and phytoplankton. The introduction of invertebrate predators (and hence intraguild predation) into the model can dampen or even reverse the top--down trophic cascade effects of fish on phytoplankton that would be predicted by simple food chain models. The level of cannibalism among the carnivorous zooplankton (the IG prey) is a key factor in determining the strength and direction of the top-down response. These results may help explain the disparate results of trophic cascade experiments. In lakes where the herbivorous zooplankton are dominated by the large cladoceran *Daphnia,* fish biomanipulation usually has a significant impact on phytoplankton biomass. This is because *Daphina* are relatively invulnerable to carnivorous zooplankton, and hence the food webs in these lakes can be approximated by simple chains. On the other hand, changes in fish planktivory often do not cascade to phytoplankton in those lakes with mostly small-bodied zooplankton. These small zooplankton are highly susceptible to predation by carnivorous zooplankton, as well as by fish. In these food webs, where intraguild predation is important, the models indicate that the top-down effect of fish on phytoplankton can be damped, or can even be the reverse of what would be predicted by simple model food chains.

Incorporating Spatial Dynamics of Fish and Fishermen in Models of Marine Protected Areas on Georges Bank

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Though they have been widely used, the impacts of marine protected areas (MPAs) on fisheries are not well understood. A lack of empirical evidence has motivated the use of computer modeling to explore their effects. The small literature that has emerged has mostly attempted to assess the impacts of closures as a proportion of a total fishery, but has largely avoided issues of shape and location of the closure or the subsequent distribution of displaced effort. Incorporating integrated and explicit spatial interactions of the biological and economic systems can be critical to understanding the impacts a specific marine protected area will have. Both the direct and indirect effects of the MPA may vary greatly with its shape and location relative to migratory patterns of fish, spatial patterns of spawning success, larval survival and dispersal, and spatial behavioral patterns of fishers. This paper presents a bioeconomic simulation model of the New England multispecies groundfish fishery that is explicitly spatial with the distribution of fishing effort determined endogenously by an empirically estimated fleet dynamics model. This model is used to demonstrate the insights that can be gained by incorporating explicit spatial dynamics into fishery models, but also to highlight some of the difficulties and drawbacks of this type of modeling. The results show that, while a marine protected area may provide protection to some species within its boundaries it may lead to increased pressure on other stocks or species as well as habitat outside the protected area. Marine protected areas may also have heterogeneous impacts on different groups of fishers creating groups that are not obvious and are revealed only with explicitly spatial models. Incorporating spatial dynamics and integrating economic behavior into fishery models greatly increases the complexity of the model. These models typically include parameters for which few data are available and may require a great deal of sensitivity analysis which can lead to ambiguity in results. The uncertainty associated with many of the parameters and processes included in explicitly spatial models suggests we must be very cautious in interpreting the results. However, these models can also be useful for identification of key parameters that drive results and testable hypotheses that will help focus empirical work. Due to the length of time it may take to see results and confounding factors such as environmental changes and other management actions, it may be very difficult to isolate the impacts of particular MPA designs. It may be more productive for empirical research to focus on increasing our understanding of critical parameters and processes which can used to improve models than on trying to directly test the results of particular MPAs.

Climate Forcing Effects on Trophically-Linked Groundfish Populations: Implications for Fisheries Management

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Commercially important groundfish populations in the eastern Bering Sea are connected to each other through the food web and act as either predators, prey, or both in the system. Some species, such as walleye pollock (*Theragra chalcogramma*), are dominant in terms of biomass and may also dominate the trophic dynamics. In addition to having different trophic roles, the recruitment patterns of these species are variable and may be related to climate forcing at either inter-annual or inter-decadal time scales. We examine the possible future effects of two levels of fishing morality ($F_{40\%}$ and no fishing) on these trophically-linked species under two different scenarios of future climate regimes using a multispecies forecast model. The model includes predation interactions between commercially fished groundfish populations and can accommodate various hypotheses about changes in mean level of recruitment and recruitment variability that might occur in each groundfish species in response to a change in climate regime.

A Monte Carlo simulation for each level of fishing mortality and each assumption on regime shift was performed using biomass ratio and yield ratio as indicators of performance. Results suggest that species respond differently to both climate change assumptions and fishing mortality depending on their position on the food web and on their generation time. Climate regime shifts produce effects comparable to the ones produced by fishing and predation interactions. Therefore accurate models for fisheries management will require considering these factors and their potential interactions. Responses are complex and difficult to predict; therefore, it is necessary to take an even more conservative approach in managing the species with the largest potential variation.

The incorporation of climate regime shifts in fisheries management will require a better understanding of recruitment behavior during a particular regime and a reliable way to identify regime shifts base on biological and or physical indices.

Multispecies Perspectives on the Bering Sea Groundfish Fishery Management Regime

(poster)

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A multispecies virtual population analysis (MSVPA) model of the eastern Bering Sea has been developed and tested. This model provides a retrospective analysis of the abundance and mortality of several groundfish species and their relationships through predation. The species included in the model are walleye pollock, Pacific cod, Greenland turbot, yellowfin sole, rock sole, Pacific herring and two external predators, arrowtooth flounder and northern fur seal. Results to date have corroborated previous work indicating high levels of predation mortality on juvenile stages of certain groundfish species, particularly walleye pollock.

Recently, a concern has been expressed about present groundfish management practices in the Bering Sea by the groundfish plan teams of the North Pacific Fishery Management Council. The plan team's concern relates to the possible ecosystem effects of different exploitation rates presently applied to various groundfish populations. Although exploitation rates of groundfish in the North Pacific are relatively conservative when compared with those in other parts of the world, walleye pollock in the eastern Bering Sea is more fully exploited relative to some flatfish species that are either not exploited or lightly exploited. We explore the possible medium and long-term multispecies implications of three different exploitation patterns (F reference, no fishing and F_{ABC}) of pollock and flatfish using the suitability estimates derived from MSVPA updated to 1998 in deterministic simulations using single species and multispecies forecasting. Three indicators, total biomass, spawning biomass and yield were used to compare the long-term effects of the two patterns of fishing mortality.

Results suggest that changes in the fishing mortality regime can indirectly affect the predation mortality of prey due to decreases of predator populations and consumption of prey. However, single species and multispecies forecasting suggest that the implementation of F_{ABC} would produce small long-term changes in the structure of the eastern Bering Sea groundfish population compared to F_{ref}. Multispecies simulation of the no-fishing scenario produced smaller growth compare to single species results, thus changing the perspective of recovery times for depleted populations.

The Cumulative Risk Initiative - an Integrated Approach to Examining Extinction Risk and Recovery Opportunities for Pacific Salmon

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Much has been written in the popular press and scientific literature about Snake River dams and salmon. Often forgotten is the fact that there are twelve Evolutionarily Significant Units (ESUs) federally listed in the Columbia River Basin, with hundreds of stocks whose populations trends have been tracked via spawner counts. If conservation planning is to proceed rationally, we need a standard method for assessing the risk faced by different ESUs and different stocks within those ESUs. Without such a standardized metric, priorities will be ad hoc.

The Cumulative Risk Initiative (CRI) has developed a series of risk measures based on a simple model of population change. Although the theory (diffusion approximations) underlying this approach is nearly a century old, the innovation adopted entails techniques for adjusting the methods to age-structured populations for which only one age class is sampled, and for which sampling error is unknown and large. By simulating data with massive errors, biases, and inconsistencies, the method was found to nonetheless aptly estimate the underlying risks. The CRI then applied this method to over 100 time series from the Columbia Basin. Among the noteworthy results was the observation that the Snake River ESUs and stocks are at less risk than many other ESUs in the Columbia Basin. Also, for some ESUs, harvest reductions would seem to offer substantial opportunities for risk mitigation, whereas for other ESUs, harvest is already so low that further reduction would yield negligible benefits.

Two general points emerge from this project. First, standard methods that are simple and easy to interpret have great value. Second, regardless of the method selected, it is essential that basic research be conducted to see how well the method performs when sampling error is large and "reality" does not exactly conform to the assumptions of the approach.

Risk Assessment for Coho Salmon using Climate Forcing in a Life Cycle Model

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A coho salmon life cycle model was developed to assess population status and relative risk of extinction for coho salmon in thirteen basins on the Oregon Coast. In the model, freshwater production is based on the habitat quality of individual stream reaches estimated from survey data. Reach-specific smolt output is a function of spawner abundance, demographic stochasticity, genetic effects, and density- and habitat-driven survival rates. After mortality and harvest in the ocean, adults return to their natal reaches to spawn. During periods of low marine survival, populations in reaches with poor habitat lose resilience when numbers decline, and demographic risk factors become more important than density dependent compensation. With favorable marine survival, high productivity reaches serve as sources for recolonization of lower quality reaches through straying of spawners. Consequently, both population size and distribution expand and contract through time. The historic time series of the Aleutian Low Pressure Index (ALPI) was used as a template to model cyclical changes in marine survival. Monte Carlo runs of 1000 iterations were used to characterize the probability distribution of potential outcomes.

The model has been applied to risk assessment of proposed harvest management regimes. Likely patterns of spawner escapement and extinction risk were modeled for 33 generations (99 years) for three harvest regimes: zero harvest, an existing escapement goal system, and a proposed exploitation rate system. The escapement goal and exploitation rate management systems were modeled with error based on the precision of available management tools. All three regimes showed cyclical abundance driven by long-term patterns in marine survival. The zero harvest regime had the highest average stock sizes, highest variability and lowest extinction probabilities, followed by the exploitation rate and escapement goal systems respectively. Median escapements in the escapement goal regime were well below the actual goal. In all cases, smaller basins and basins with poorer quality habitat showed higher extinction probabilities. Currently we are developing improved climate-related survival indices for both marine and freshwater. Time series of these indices, projected using climate models, will be used to produce patterns in survival incorporating climate change for use in future risk assessments. Models of this type accumulate variability in natural systems and uncertainty in management processes across the salmon life cycle. They are potentially useful in specifying both short and long term risks of management options in the context of our understanding of salmon biology.

Rebuilding Plans for an Uncertain Stock-Recruitment Relationship, Red Grouper in the Gulf of Mexico

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In general, marine fisheries in the southeast United States are characterized by relatively short time series of data available for estimation of stock recruitment relationships. These short time series mean that there are often many equally probable relationships between stock size and recruitment that can be hypothesized. For example, Beverton and Holt stock recruitment relationships with maximum recruitment well above the observed data can often have the same residual sum of squared deviations as relationships with maximum recruitment at the average of the observed levels of recruitment. These two maximum recruitment hypotheses could correspond to levels of fishing mortality the stock has experienced prior to the start of the time series or to changes in the carrying capacity of the habitat. These different hypotheses do not in general change the estimation of current stock size and fishing mortality rates, but do have a major impact on the maximum sustainable yield calculations, and by extension, the status determination for the stock.

Changes in the stock recruitment relationship can change the status of the stock from overfished to not overfished and also change the management measures required for a rebuilding plan. Using a flexible forward projecting age structured assessment program, ASAP, we demonstrate the latter situation for the case of red grouper in the Gulf of Mexico emphasizing the non-continuous rebuilding time calculations and the impact on different management strategies. The non-continuous rebuilding time calculation is due to the 10 year rule. First, the time for rebuilding under no fishing (T_{min}) is calculated. If T_{min} is less than 10 years, then the rebuilding time (T_{max}) can be no more than 10 years. However, if T_{min} is greater than 10 years, then T_{max} is T_{min} plus one generation time. Thus, there is a large difference in rebuilding time between a case when T_{min} is 9 versus 11 years. For a given set of spawning stock and recruitment observations, lower maximum recruitment in the Beverton and Holt relationship in general translate into smaller T_{min} values. Considering a range of possible values, as in the red grouper analysis, will often lead to a sudden change in regulatory measures required for rebuilding as T_{min} approaches and then exceeds 10 years.

Suggestions for dealing with these different hypotheses are presented which create a control rule based on assessment results every few years and the status of the stock under each hypothesis. The goal is to acquire sufficient information to either reduce the number of hypotheses or allow for recovery of the stock under all of them while still maintaining a viable fishery.

Ecosystem Considerations in Fisheries Management: Linking Ecosystem Management Goals with Ecosystem Research

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As fishery management organizations move towards ecosystem-oriented management, there is a need to more clearly define the ecosystem management goals of the organizations and the tools available to managers to attain those goals. Parallel to this must be an expansion of the scientific advice provided to management beyond traditional single-species stock assessment advice. Although there have been advances in multispecies and ecosystem modeling approaches, these approaches have not yet been completely embraced by the fishery management community. In some cases this is so because of the difficulties of validating these models and, in other cases, because of the lack of sufficient data and knowledge of the critical processes to develop an appropriate model. Progress can be made, however, in providing ecosystem advice to managers while we wait for these approaches to mature. The burgeoning GLOBEC and GLOBEC-like research efforts going on throughout the world, increasing emphasis on habitat research, ongoing trophic interactions work, and long-term monitoring of non-commercial species all provide useful information on ecosystem status and trends. Some of this ecological information can be used to gauge the success of various management schemes that have been put in place to meet ecosystem management goals. The North Pacific Fishery Management Council (NPFMC) has started to include some of this ecosystem research information in an ecosystems considerations document that supplements the traditional single-species stock assessment reports.

We have recently completed a revision of the ecosystem considerations document of the NPFMC. This document now contains many parts of a Fishery Ecosystem Plan recommended by the NMFS Ecosystem Advisory Panel such as ecosystem status and trend information for many ecosystem components. It also has management indicators such as the amount of habitat closed to fishing, changes in the amount of fishery discards over time, and the trophic level of the catch. This document provides a way for ecosystem research scientists from a variety of organizations to inform stock assessment scientists of their results and for managers to link management actions with ecosystem observations and ecosystem-based management goals. Future work includes the development of more quantitative management objectives and ecosystem indicators.

The Influence of Spatial Dynamics on Predation Mortality of Bering Sea Walleye Pollock

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Walleye pollock is a dominant member of the groundfish community in the eastern Bering Sea and it provides the largest contribution to the groundfish catch in this region. Walleye pollock also plays a central role in the eastern Bering Sea food web, integrating secondary production and serving as a prey source for groundfish (particularly Greenland turbot, arrowtooth flounder, Pacific cod, and Pacific halibut), marine mammals, and birds. Juvenile (age 0 and 1) walleye pollock also provide an important prey source for adult pollock and, due to the large population size of pollock, the amount of energy moving through this cannibalistic pathway exceeds consumption by any other predator.

Previous studies have estimated spatially aggregated predation mortality rates on pollock either from field data or age-structured population models. However, it is plausible that pollock population dynamics differ by spatial location. The observed catch data suggest ontogenetic movement of pollock. For example, the strong 1989 year class was first observable at ages 2 and 3 on the outer EBS shelf, but at age 4 on the cental EBS shelf. Strong year classes of pollock are often observed when pollock adults and juveniles are spatially separated (Wespestad *et al.* 1999).

The BORMICON model was used to examine spatial cannibalism of pollock. BORMICON is a spatially explicit population model originally developed in Iceland to study BOReal MIgration and CONsumption of Icelandic cod and capelin. Several population processes in a particular spatial location are modeled, including consumption by and upon fish, harvest, growth, and maturity. The model also describes movements of fish between spatial locations using discrete time steps. The spatial distribution of pollock, by age, observed in the EBS surveys was used to develop the BORMICON migration matrices. Harvest can be modeled in BORMICON either with a functional relationship, or a direct removal of biomass from the population. The latter option was chosen for this study because of the existence of pollock harvest by area, year, and size group.

Some preliminary model runs reveal the sensitivity of estimated predation to migration. Without migration matrices, most predation of one year old pollock occurs in nearshore and southern areas that have relatively warm temperatures. When migration is included, most consumption occurs in northern offshore areas, consistent with the spatial distribution of age 1 and 2 fish.

This work is our initial attempt to model the spatial aspects of predator-prey interactions. Model refinement will be a long-term process that involves improving our biological sampling to appropriately sample at finer spatial scales, and increased field and lab research on animal behavior and movement patterns.

Designing Fishery Management and Stock Rebuilding Policies for Conditions of Low Frequency Climate Variability

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Development of optimal management policies requires more information than is presently available on the properties and patterns of low frequency environmental variability. As a rough approximation especially appropriate to portions of the west coast, consider that fish resources experience alternating regimes of high and low productivity, with each condition lasting about 30 years. At least three regimes must be experienced in order to distinguish the effects of population size from the effects of the environment, indicating that over 60 years of information may be required to address management of individual fisheries.

For resources that undergo extreme fluctuations in abundance, constant harvest rate management performs suboptimally under conditions of low frequency variability in productivity, even when recruitment can be predicted accurately. Optimal policy requires the harvest rate to change in order to match the productivity level characteristic of the regime state. There is a yield benefit to delaying the change to the alternate harvest level by a few years; a similar delay can be achieved by linking the harvest rate to a moving average of an appropriate environmental indicator. Such a policy has been implemented for the sardine (*Sardinops sagax*) stock off the west coast of the United States, wherein the harvest rate is determined by the average sea surface temperature for the preceding three years.

Long-lived species such as some rockfishes (*Sebastes* spp.) can buffer the effects of low frequency environmental variability by living longer than the duration of unfavorable conditions and by recruiting at an advanced age. The biomass of a model population with M=0.05 and median age of recruitment at 10 years varies nearly opposite in phase from the environmental pattern described above: peak biomasses occur about midway through the unfavorable period, and lowest biomasses occur midway through the favorable period. In this case, a constant fishing rate produces nearly the same average yield as an environmentally-dependent rate, and with relatively low variability.

Regime shifts tend to be associated with severe depletion of fish stocks, especially when the harvest rates and fishing capacity built up during productive conditions cannot be sustained during subsequent periods of low productivity. Rebuilding depleted fish stocks can require decades, and will be most effective during favorable periods. Rebuilding may be virtually impossible during prolonged unfavorable periods.

Further complications may arise in multispecies systems such as the rockfishes (*Sebastes* spp.) where size-specific harvesting patterns remove larger long-lived species, leaving smaller species that prey upon juveniles of both species. A simulation of such a two-species system where predation by the large long-lived species (described above) normally controls the abundance of the small species, indicates that the large species has an F_{MSY} that is 15% of what would be indicated by a single-species analysis. The single species production curve shows B_{MSY} to occur at 46% of $B_{unfished}$, but the two-species model shows B_{MSY} to occur at 57% of $B_{unfished}$. Rebuilding an overfished stock of the long-lived species would require centuries.

Are there Ecosystem Analogs to Overfishing Definitions?

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Concepts of overfishing and associated quantitative definitions thereof are based in single-species theory and practice. Given the increasing interest in the implications of direct and indirect effects of harvesting on assemblages of species and communities, it is appropriate to consider ecosystem analogies to standard overfishing definitions. Two important considerations in the use of definitions of overfishing at any level of systematic organization are (1) the ability to quantify and measure performance of the biological system relative to the definition, and (2) incorporation of definitions, that if achieved, would produce greater benefits (however defined) than if the reference points are exceeded. Incorporating ecosystem considerations into fisheries management can be accomplished by modifying existing single-species overfishing paradigms or developing new approaches to account for ecosystem structure and function in relation to harvesting. While existing overfishing concepts have a strong theoretical basis for evaluating policy choices and much practical use, they do not provide direct guidance on issues such as biodiversity, serial depletion, habitat-modifying effects of fishing methods, or trophic-level impacts of fishing. There is, however, little basis for defining optimum fishing using related metrics such as diversity indices, slopes of size or diversity spectra, or average trophic level, and these may produce ambiguous results (e.g., the same value of the control variable can be produced by two or more different system states). For ecosystem-based overfishing concepts to assume a greater role in management, quantifiable, predictive, and unambiguous measures of ecosystem state and flux must be developed to index: (1) biomass and production by the ecosystem and its important parts, (2) diversity (at various levels of organization), (3) patterns of resource variability, and (4) social and economic benefits. Rather than substituting for existing overfishing concepts, ecosystem considerations should be used to evaluate and modify primary management guidance for important fisheries/species, in all likelihood further emphasizing the need for management of fishing capacity, supported by increased use of technical measures such as marine protected areas and gear restrictions.

Analysis of Environmental Factors on Swordfish (*Xiphias gladius*) Catch Rates by Sex and Age from the U.S. Longline Fleet 1992-1998.

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Catch, size and effort data collected from the U.S. longline fleet operating over a wide geographical range of the western north Atlantic Ocean have been used to develop indices of abundance. Since 1992, the Pelagic Observer Program has recorded detailed information on gear characteristics, location and time of gear set and retrieval, environmental conditions, morphometric (length and weight) and sex identification data. From 1992 to 1998, a total of 2,500 longline sets were recorded with swordfish accounting for about 30% of the total species reported. Relative indices of abundance of swordfish were estimated using a Generalized Linear Modeling (GLM) approach assuming a delta lognormal model distribution. The delta model assumed a binomial error distribution for modeling the proportion of positive sets, and a log-normal error distribution for modeling the mean density or catch rate of successful sets. The following variables were included in the analysis of swordfish catch rates: year, age, geographical area, season (trimester), target species, day or night sets, depth of longline, duration of the haul (or soak time), number of light-sticks per hook, density of hooks per unit length of main line, sea-surface temperature, and operations procedure (OP, the factor that categorizes each vessel according to their gear and fishing operation characteristics). A step-wise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed variability. Deviance analyses showed that OP, area, target and light-sticks were the most important explanatory variables for both model components. OP was by far the most important factor, particularly for the mean catch rate of positive observations, accounting for 40-60% of the deviance explained by the model. This result shows that longline fleet characteristics (such as boat-size, fishing techniques, main geographical area of operation) are the primary factors determining swordfish catch rates.

The pelagic observer data also included some environmental factors (day/night, sea surface temperature, and SST) and other fishing related features (depth of gear, soak time, and hook density). None of these factors were important in explaining overall deviance in the models, although in some cases these were statistically significant. In a analogous study, Bigelow *et al.* (1999) found that latitude, longitude, lunar index, SST, and SST frontal energy were important environmental variables in explaining swordfish catch rates in the North Pacific (U.S. longline off Hawaii). Latitude and longitude are evidently correlated with area in our analyses. The SST factor was described as an "intermediate effect" in Bigelow's report; in the present study, SST was a statistically significant factor (especially in the proportion of zero/positive swordfish catch sets) but it accounted for less than 5% of the total model-explained deviance. Neither depth, soak time, nor hook density accounted for any significant percent of the model- explained deviance for the observer data. The lunar index was not investigated in the present study. It could be argued that seasonal and area factors in these types of analyses account for environmental influences to a large degree, but that the added amount

of variability in catch rates accounted for by typical "environmental variables" as measured by such factors as above, may not be large since the operations of fishers are often guided by experience gained from fishing that already makes use of environmental correlates with the fishers probability of success, thus limiting the variability in catch rates attributable to measures made in this way.

Overall, the final models explained between 41-51% of the variability within the proportion of positive/total sets for the observer swordfish data, and 48-50% of the variability within the mean CPUE rates for positive catch sets. At least some proportion of the error variance could be attributed to unmeasured environmental influence.

Importance and Impact of Predation on the Dynamics of Atlantic Herring

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We examine the impact of predation on the coastal stock complex of Atlantic herring found on the eastern USA shelf. Stomach data indicate that herring are an important item in the diet composition of twelve piscivorus fishes. Predatory fish responded to the abundance of herring during periods of high and low abundance during 1977-1997 as reflected by major changes in the proportion of herring in their diet. Consumption of herring by this suite of predators peaked at over 250,000 MT in the early 1990s and then began to decline in spite of continued increases in herring abundance. Consumption was related to the abundance of herring and the twelve predators. Length composition data from predators and the herring fishery indicate considerable overlap in the two components, suggesting competition for the same fish. Results from a trial VPA, with predation modeled as an additional fishing fleet, suggest that predation mortality rates (M2's) at age are time variant and can be much larger than the constant M that is used in the current assessment. Trial projections indicated that the current single species assessment approach may be too optimistic when used in predicting yield and spawning stock biomass. Conclusions related to trophic considerations suggest that predators may consume herring relative to its abundance and that the flow of herring to predators is probably large. Consumption may also exceed landings for this species, especially in the case of a fully rebuilt ecosystem with large biomasses of predators. It also appeared that herring consumption declined in the late 1990s as the major predators such as cod and spiny dogfish were overfished. Relative to assessments of the herring stock complex, yield projections may in some cases be too optimistic when predation is not included. For a species like herring it may be difficult to maintain stock biomass targets with single species biological reference points due to the influence of predation. In addition, major stock declines may be more probable if stocks like herring are fished at high rates of exploitation.

Yield versus Forage Consideration in the Regime-Dependent Pacific Sardine Fishery: a Comparison of Results from Management and Migration/Forage Models

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There is now extensive evidence that the North Pacific undergoes extensive decadal scale climatic variations. This is nothing new to those who have worked on the California sardine. Paleo-sediment analyses carried out decades ago clearly showed that the California sardine averaged a bit less than two population outbreaks per century for at least several thousand years. The last peak, during the warm regime in the 1930s, resulted in a peak biomass of over 4 million MT. Adverse, cold climatic conditions, extensive overfishing and a failure in fisheries management resulted in a stock biomass of less than 0.004 million MT extending from 1965 until the early 1980s. Following the regime shift in 1976-77, the biomass increased very rapidly at an average rate of over 50% per year and, although this rate has declined sharply in recent years, the current stock synthesis models suggest that biomass exceeded 1 million MT in 1999.

Fishery management and the modeling methodology on which it is based has centered on the idea that the environment is stationary and with this is a given that somehow we can find the "optimum" fishing mortality rate that will stabilize a species population size and fishery. Decadal/regime scale climatic variability and the resultant productivity changes observed in the California Current suggests that the ecosystem response to non-stationary physical forcing factors will not allow this.

Two simulation models of the California stock of Pacific sardine, both utilizing regime fluctuations with productivity forced by highly structured time series of sea surface temperature are compared in this presentation. Can this be done in 20 minutes?

The first is the simulation model that Larry Jacobson and I used to develop harvest policy options for the Pacific Fishery Management Council (PFMC) coastal pelagic FMP. This model shows that the highest long-term yield from the sardine stock occurs with a pulse fishery which takes 45% of the biomass over 1 million MT and stops the fishery whenever the biomass drops below 1 million MT. This strategy results in 49% of the years with no fishery. The policy recommended by the plan development team and accepted by the Council puts major emphasis on two factors: the median yield from the fishery and the average biomass level of the stock. This last factor is highly significant in major forage species such as sardine. The second model is a nine box, latitudinal model (Central Baja California to Queen Charlotte Sound) that simulates the distribution of sardine under different temperature conditions based on age, season and temperature dependent migration rates. Natural, and fishing mortality are accumulated by region to allow an assessment of the volume of forage that the stock contributes to the several regions during warm and cold regimes.

Effects of Peak Flows on Chinook (*Oncorhynchus tshawytscha*) Spawning Success in two Puget Sound River Basins

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Freshwater habitat conditions at the earliest life stage can be a constraint to salmon (*Oncorhynchus* spp.) productivity in the Puget Sound. Lower egg-to-fry survival rates and smolt production estimates have been correlated to larger flood events. We analyzed the relationship between peak flows during the egg incubation period with six different Skagit and Stillaguamish River chinook stocks to investigate whether the effects of peak flow during egg incubation constrained chinook production at the adult life stage. Our measure of adult production used was a chinook spawning recruitment ratio, which is the number of spawning adult chinook to returning adult chinook for a brood year. We transformed peak flood events into a flood recurrence interval (years) and developed a general model of chinook egg to migrant fry survival from these data. The model was applied to Stillaguamish River summer chinook data in order to investigate the sensitivity of chinook egg to fry survival to changes in peak flow hydrology.

We found that six different stocks of Skagit chinook and one stock of Stillaguamish chinook were unable to produce enough return spawners to "replace" themselves if peak flow during the egg incubation period was equivalent to a 15-year event or larger. A 15-year flood recurrence interval corresponds to a 5% chinook egg to migrant fry survival rate. Egg incubation survival limited chinook recruitment almost 20% of the time, suggesting that the egg to fry life stage of the chinook life cycle can limit adult production even when flooding is not severe. In the North Fork Stillaguamish River, increases in peak flows over the last 70 years have changed the flood frequency curve. We hypothesize chinook egg to fry survival has been reduced from 10% to 5% for the two-year flood event. Every brood year of spawning chinook currently has a 50% chance, rather than a 10% chance, of being exposed to flow events that correspond to egg to fry survival rates where the stock does not replace itself.

Freshwater habitat conditions at the egg to fry life stage can be a "bottleneck" to production of chinook stocks. A change in peak flows can reduce egg to fry survival levels to the point where one generation of chinook cannot produce enough returning adults to replace themselves. This information is important in predicting run sizes for fisheries harvest management, and has significant landscape management implications when considering how to protect and restore chinook stocks.

Advances in Evaluations of Red Drum Resources in the Gulf of Mexico

(poster)

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The red drum (*Sciaenops ocellatus*) is a large sciaenid found throughout the coastal waters of the Gulf of Mexico and along the eastern seaboard as far north as Massachusetts. It has long been highly prized by recreational anglers and had supported a modest commercial fishery since at least 1880. In the mid 1980's, however, market demands for 'blackened redfish' triggered a rapid increase in commercial effort targeting the spawning aggregations of adults. This raised concerns that the stock would collapse, prompting the Secretary of Commerce to implement an emergency rule in 1987 that prohibited all commercial harvest of red drum in the EEZ. Nevertheless, fishing pressure has remained high in the Gulf of Mexico owing to a large inshore recreational fishery that focuses mostly on juveniles. This paper applies an age-structured, length-based model to catch, survey, age composition and length composition data for Gulf of Mexico red drum. The model embeds standard population dynamics equations within a maximum likelihood statistical estimation framework. While such statistical models are certainly not new to fisheries science, having been widely used for more than 20 years, they are new to the Gulf of Mexico Fishery Management Council, where they have met with considerable suspicion. For this reason, the model for red drum was kept as simple as possible. Even so, some departures from canonical techniques were needed to accommodate certain features of the red drum fishery. The most important of these were seasonal selectivity coefficients for each fishery (to account for the very rapid growth of juvenile red drum) and the use of truncated probability density functions to model the distribution of length at age with minimum size regulations. The results suggest that the current level of fishing exceeds the fishing mortality rate associated with a 30% equilibrium spawning potential ratio (SPR) and that the current level of spawning stock fecundity is well under the corresponding equilibrium value at 30% SPR. However, the analysis is quite sensitive to the weights given to certain data sets, particularly the surveys of adult biomass and estimates of bycatch from the offshore shrimp fishery, which are very imprecise and possibly biased, but without which no assessment is possible.

What can Spatial and Metapopulation Components Add to a Life Cycle Salmon Model in Determining Risk Assessment?

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Spatial processes are an important aspect of salmon population dynamics, from freshwater spawning and rearing habitats and juvenile migration patterns, to estuarine and coastal rearing areas and mature migration routes back to the freshwater. The availability, health, and general condition of habitat throughout the life history of salmon is recognized as integral to the study of ways to recover depressed populations, especially as it becomes obvious that fishing restrictions alone will not be enough to improve salmon runs in the Pacific Northwest. The Salmon Analysis Team at the Northwest Fisheries Science Center has developed a model to explore the relationships between freshwater habitat characteristics and production of salmon from a watershed, taking into account the full life histories of, and interactions between, the populations originating within the watershed. This approach involves metapopulation dynamics; that is, the dynamics of spatially distinct populations that influence each other through spatial interactions such as straying.

The model was originally developed for coho salmon in the Alsea River watershed in coastal Oregon. We are currently in the process of developing a model for chinook salmon from the Skagit River watershed of Puget Sound. In both the Alsea River and Skagit River, degradation of freshwater habitat is considered to be one of the factors leading to salmon decline. The aim of this modeling research is to provide a tool that can help prioritize salmon restoration efforts by relating them to the survival potential of salmon populations within tributaries, for the whole watershed, or at the Ecological Significant Unit level used in the Endangered Species Act process.

Tunas and the Environment: the ICCAT Perspective

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At ICCAT, renewed attention is being given to environmental affects on the status and future prospects of stocks of Atlantic tuna and tuna-like species in the face of fishery removals. Although the current state of the art remains with correlative evaluations, ICCAT's scientific committee (SCRS) has recommended that the influence of the effects of the environment on tuna biology and vulnerability to fisheries should be better integrated into assessment analysis with the aim of improving the predictive power of assessments. The current state of activity on the topic at ICCAT is reviewed through studies relating to assessments of north Atlantic albacore, north Atlantic swordfish, and Atlantic bluefin tuna.

Santiago (1998) examined correlations between the North Atlantic Oscillation (NAO) and temperate tuna recruitment patterns. The highest correlation that he observed was for north Atlantic albacore with a negative correlation between recruitment and the intensity of the NAO in the winter. He noted that a similar correlation had been found with North Pacific albacore and suggested that in the North Atlantic, stormier and cooler conditions in the albacore spawning area were associated with increased recruitment. So far, the ICCAT scientific committee has not included environmental effects in models used to formulate management advice for north Atlantic albacore.

Mejuto (1999) reported on correlations between north Atlantic swordfish recruitment and the NAO, and ICCAT's scientific committee conducted additional analyses to investigate that relationship. Mejuto (1999) showed that a Spanish index of abundance of 1 year old swordfish was negatively correlated with the NAO in the previous year. The SCRS noted that NAO indices from different times in the year were only moderately correlated. We show that survivorship (recruits/spawners) was only weakly correlated with the winter NAO. The SCRS noted that if the NAO actually does influence swordfish recruitment, then under favorable NAO conditions even substantial increases in catches would permit recovery to target stock levels within 10 years. However, the SCRS noted the recent NAO indices suggested less favorable conditions for north Atlantic swordfish recruitment, and the scientific committee did not incorporate assumptions about future NAO states in its management advice.

For west Atlantic bluefin tuna, the ICCAT scientific committee has included assumptions about environmental effects on stock-recruitment relationships in its management advice. The committee has presented two sets of advice to managers - one assuming that a regime shift has occurred in the stock recruitment relationship (with low levels of recruitment since the mid 1970's) and another assuming that no shift has occurred. Santiago (1998) indicated that a weak negative correlation existed between west Atlantic bluefin recruitment and the NAO. We observe weak positive correlation between survivorship (recruits/spawners) and the NAO and a stronger negative correlation between survivorship and catches of large spawners.

Logbook Data From the Menhaden Purse-Seine Fisheries: Improving Estimates of Catch-at-Age and Other Applications

(poster)

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By volume, the reduction purse-seine fishery for Atlantic menhaden, *Brevoortia tyrannus*, is the largest fishery on the U.S. East Coast. Landings since 1995 have averaged 262,000 metric tons, and may annually account for up to 40 percent of the fisheries landings on the eastern seaboard. Since 1955, the National Marine Fisheries Service at the NOAA Beaufort Laboratory has monitored the Atlantic menhaden fishery for landings, fishing effort, and port sampling information. Data from weekly port samples are combined with landings to generate a catch-at-age matrix. Stock assessments are performed annually as required by the Atlantic menhaden FMP.

Port sampling protocols for the menhaden fishery have been relatively consistent with only slight modifications since the 1950s. Beginning in the 1970s, fleet fishing patterns changed, and programmatic assumptions and estimates of catch-at-age became suspect. Menhaden vessels have maintained logbooks called Captains Daily Fishing Reports, or CDFRs, since the late 1970s, and vessel participation is near one hundred percent. Among other information, CDFRs enumerate for each purse-seine set: time and location of set, estimated fish catch, and direction and distance from shore. Menhaden Program staff began computerizing CDFRs in 1992, and complete CDFR data sets are available for 1985-99 on the Atlantic coast. Atlantic CDFR data sets have been used to improve annual catch-at-age matrices. CDFR data bases may have additional utility for ecosystem and trophic modeling. For example, striped bass-bluefish-forage fish interactions have long been a source of controversy in the Mid-Atlantic Bight. CDFRs provide accurate documentation of geographic removals by commercial harvesters of a major forage species. Moreover, quota-based management has been recommended for the Atlantic menhaden stock. CDFR data bases could provide insights into fishing controls by age and/or area.

The Bycatch and Mixed Species Yield-Per-Recruit of Flatfish Fisheries on the Eastern Bering Sea Shelf

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Single-species age-structured stock assessments are used to set management advice for several eastern Bering Sea (EBS) flatfish in the federally managed groundfish fishery. These include yellowfin sole (*Limanda aspera*), rock sole (*Lepidopsetta bilineata*), flathead sole (*Hippoglossoides elassodon*), and Alaska *plaice (Pleuronectes quadrituberculatus*). These species, along with Pacific halibut *(Hippoglossoides stenolepis*), occupy similar habitats on the EBS shelf and co-occur to varying degrees in the harvest. Additionally, the retention of Pacific halibut is prohibited in the federally managed groundfish fishery and quotas of halibut bycatch, not the directed target quotas, have been the main factor in restricting the fishery in recent years. However, little published information exists regarding bycatch in the EBS flatfish fisheries. In this work, we describe the catch composition of the various EBS flatfish fisheries and use multispecies yield per recruit and multispecies spawning stock biomass (SSB) per recruit models to consider fishing mortality reference points that incorporate technological interactions.

Estimates of flatfish catch and trawling effort in the EBS from 1995-98, by fishery, were made from the North Pacific groundfish observer program. The definition of fisheries was based upon the catch composition within a vessel-day. Standardized effort was used to derive catchability coefficients by species and fishery. The catchability of the yellowfin sole fishery on Pacific halibut was higher than other flatfish fisheries, although the standardized effort was higher.

The multispecies yield and SSB models, scaled by the mean recruitment of the post-1977 year classes, revealed that the recent average species yields for the four flatfish species above range from 30% to 83% below the equilibrium yields expected at $F_{40\%}$. Further, the models revealed that it is not generally possible to simultaneously achieve the target $F_{40\%}$ yields of flatfish given the recent patterns of bycatch. Drastic reductions in halibut catchability may be necessary to prevent limitation of the flatfish fishery under the current halibut bycatch limit of 3675 t for EBS trawl fisheries. Future research should focus on evaluations of alternative gear types (i.e., halibut excluder devices), as well as identifying an optimal level for the halibut bycatch limit.

Evaluation of Single-Species Versus Multi-Species Models in the Context of Managing for Maximum Sustainable Yield

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Most stock assessment models do not contain explicit linkages between species. Of course, species in a real ecosystem do interact, which raises the question of whether it might be preferable to structure stock assessment models so as to contain such linkages. To address this issue, an evaluation was conducted in which both multi-species and single-species assessment models were applied to sets of data generated by a multi-species simulation model. The simulation model contained three species and two target fisheries. Each species was linked to all other species through predator-prey interactions and each target fishery was linked to all species through bycatch interactions. All parameters were drawn randomly from statistical distributions, subject to the constraint of non-negative equilibrium abundance for all species and ages given the historic average target-specific fishing mortality rates. Population dynamics were simulated with process error for all species and ages, and data were simulated with observation error for all species and ages. The multi-species assessment model was identical in structure to the simulation model, whereas the single-species assessment model assumed that all predation and bycatch rates were zero. In both the multi-species and single-species assessment models, the mode of the joint posterior density was used to estimate all parameters. Both assessment models were used to project a target catch for the coming year using two different harvest control rules: a "constant F" control rule in which the target fishing mortality rate was equal to the maximum sustainable yield (MSY) rate regardless of projected stock size, and a "variable F" control rule in which the target fishing mortality rate varied proportionally with projected stock size whenever the latter was less than the MSY level. In the single-species assessment model, MSY was defined in the usual way, whereas in the multi-species assessment model, MSY was defined as the largest possible equilibrium catch summed over all target species, subject to the constraint of non-negative equilibrium abundance for all species and ages. The simulation-assessment-projection cycle was run 100 times. The central results were as follow: (1) The multispecies assessment model tended to give essentially unbiased estimates of the MSY exploitation rate, MSY biomass, and target catch. (2) The single-species assessment model tended to under-estimate the MSY exploitation rate, overestimate MSY biomass, and slightly overestimate target catch under the constant F control rule, but tended to give essentially unbiased estimates of target catch under the variable F control rule.

Investigating Essential Fish Habitat for West Coast Groundfish

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West Coast groundfish fisheries are currently in crisis with several groundfish stocks severely depleted. In addition, we currently have only enough information to determine the status of 16 out of 82 commercially important species, but even for those species, our assessments have not been sufficiently precise or frequent to sustain healthy stocks. Some important contributing factors which limit our ability to accurately assess the current status of West Coast groundfish include: (1) climatic effects on the productivity within the California Current system and related assumptions in assessing stocks, (2) inaccuracies in estimating catch and bycatch, (3) spatial and temporal limitations in sampling (e.g., seasonality and coverage), (4) habitat loss and degradation, (5) inappropriate assumptions concerning stock structure, and (6) habitat-restrictive survey methodologies. While the Northwest Fisheries Science Center (NWFSC) is currently making strides in all of these areas, this presentation will focus on our new program in habitat studies that will address the effects of mobile fishing gear on benthic habitats, identify habitat areas of particular concern, and incorporate habitat associations in assessments. The following example of ongoing research off Oregon will illustrate developments in this area.

The NWFSC and NOAA OAR's Pacific Marine Environmental Laboratory are working with investigators from several government and academic institutions on an interdisciplinary study of the habitats of groundfish on and near Heceta Bank, Oregon. Heceta Bank is the largest and most important of the heavily fished rocky banks on the outer continental shelf off Oregon and has been the site of several historical studies of groundfish and their habitats. In the late 1980s, 58 submersible dives on Hecata Bank characterized the species composition of the bank and provided important data on relationships between fish species and bottom type. In 1998, a multibeam echosounder survey of Hecata Bank provided a highly detailed, precisely navigated, seafloor map of bathymetry and seafloor texture that serves both as a context for the historical data set, and as a basis for a more comprehensive study of groundfish/habitat relationships over a larger area. During upcoming summers, we will employ both a manned submersible and remotely operated vehicle to revisit the sites surveyed in the late 1980s. Comparison of these new survey data to historical data and additional seafloor surveys will: (1) lead to a model approach for characterizing and quantifying habitat associations of benthic animals on a scale meaningful to the stock assessment of commercial species, and conservation of benthic communities, and (2) provide a unique opportunity to examine the possible impact of a decade of intense bottom fishing at a critical place on the outer continental shelf of the Northwest United States.

A Comparison of the Accuracy of Alternative Maximum Likelihood Length-based Stock Assessment Methods

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Modern fishery stock assessment models can be classified into two major types of population models, length-based models and age-based models. Age-based models are a preferred choice due to simplifications of annual calculations. However, age information can be difficult to obtain and may be inaccurate. Often, length information is easy to obtain and more accurate compared to age information. In addition, population and fishery parameters such as maturity, mortality, and gear selectivity are frequently dependent on length more than age information. Most research in the past has focused on adding growth variability via some type of stochastic growth function or age to length transformation. Previous researchers have discussed the properties of stochastic growth functions and indicated that most length-based models inherently assume variation in growth is due to environmental forces, as opposed to genetic variation. Variation in growth due to environmental forces or genetic forces is analogous to measurement and process error properties in statistics, respectively.

We present a new population model in which we cast growth as a genetically variable process. The reason for choosing to model variability in growth as a genetic process is an attempt to capture the effect of size-specific removals, in particular the harvest of large individuals, on the population. The degree to which this effect is important in population dynamics is dependent on the level of fishing mortality, the amount of variability in growth, and the steepness of the size selection curve. We have developed an extension of age-structured population modeling using the AD Model Builder software which accounts for both age and length information by projecting growth via a Goodman-like growth transition array. For this population model, growth in length for each age was modeled by a simple set of von Bertalanffy growth models defined by a set of different L_∞ and K parameters having a joint bivariate normal distribution.

Our model output is compared to estimates from the stock synthesis model commonly employed for U.S. West Coast groundfish. Model estimates of recruitment and biomass were compared to the known values from an individual-based model simulation of two datasets. In the case of both datasets, our model produced slightly less biased recruitment estimates with mixed results for total biomass estimates. These results are preliminary and future research is planned to explore up to 10 different datasets with varying growth and fishery properties.

Use of Surficial Sediment Information and Species Assemblage Analysis for Improving Trawl Survey Stratification and Abundance Estimation

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While the US west coast triennial bottom trawl shelf survey has been conducted eight times (1977-1998) and the data have been analyzed according to a system of latitudinal and bathymetric strata, the actual utility or effectiveness of the strata in increasing biomass estimate accuracy and precision has never been tested. Our goal was to determine the location of the most distinct species assemblages and their habitat types, and to compare assemblage locations with the stratification scheme.

Although several species assemblage analyses have been conducted on the US west coast, often utilizing triennial survey data, our intent was to conduct the first analysis using ecologically relevant species of fish instead of the most abundant or most commercially valuable species, to divide some species of fish into different length categories instead of pooling all size groups together, and to include invertebrates which can be important constituents of the bottom community. As the analysis progressed, similar species-size groups were combined to reduce errors and to increase sample size through an iterative clustering process. Next, we conducted a similar clustering analysis to determine the stations with the most similar species and plotted each station cluster on a map.

We were interested in describing each station cluster by the habitat of the ocean floor, but found that the available habitat maps were inadequate. By combining numerous data sets from previously conducted sediment research projects in a fuzzy logic database, we constructed our own map of sediment types, covering much of the triennial survey area. This data rescue project now contains several thousand sediment data points, making it the most comprehensive resource on west coast continental shelf marine habitats, and represents the results of about $10,000,000 in field work.

We used a GIS to derive sediment values for each trawl survey station because the two data sets were spatially disparate, mapped each station assemblage, and described each assemblage in terms of water depth, water temperature, geographic range, and sediment type. Approximate boundaries of each assemblage will be compared to the stratification scheme.

DISCUSSION GROUP REPORTS

SUBTHEME I: ECOSYSTEM PROPERTIES

Discussion Leaders & Rapporteurs: ***Bill Overholtz (NEFSC), Jason Link (NEFSC), and Steve Murawski (NEFSC)***

Goals and Objectives

Ecosystem properties include biodiversity, species and size composition, species diversity, genetic diversity, and a wide variety of products and services including food, income and recreation.

The group discussion centered on the importance of clearly defining goals and objectives for ecosystem-based management (EBM), formulated in terms of relevant ecosystem properties. There was consensus in the group that we should retain single-species approaches, but that in many cases additional ecosystem and ecological inputs are required for EBM. This may necessitate a hybrid approach, combining and borrowing features from single-species approaches, multispecies approaches, and systems ecology. The general feeling of the group was that we should be doing fishery management (top down) with ecosystem considerations included, as opposed to attempting ecosystem management (bottom up). The group felt that many potential factors are not controllable, such as biodiversity, but that they may be monitored. As a general point of interest, the group asked the question, "are our current problems a result of the failure of single-species approaches or a failure of fisheries management?" The consensus was that in many cases there has been a general failure of fisheries management, not the science and advice. The group felt that sustainability is a primary concern, and that there is a need to expand the management time frame to preserve future opportunities and options. In this regard, keeping impacts and perturbations as small as possible was also considered to be important.

Metrics

Metrics for monitoring and measuring ecosystem properties were presented and discussed. Many metrics are available for indexing the status of ecosystems at several hierarchical levels, but a thorough analysis of the performance of metrics is needed. Currently, a lack of quantification is a serious impediment to using any of the common ecological metrics. The group was unwilling at this time to translate these metrics into "ecosystem overfishing" reference points, control rules, or standards. There was general agreement that a decision table or "consumer reports" type approach is possible and may be a useful tool. Some participants felt it was important to emphasize that ecosystems are not all created equal, that it may be important to monitor different processes in different systems, and that there are data poor and data rich systems. The group agreed that further studies of important and key emergent properties of ecosystems is warranted. The group recommends that a workshop be conducted to further explore the utility of metrics for ecosystem based advice. The group recognized that some of the common ecological metrics in use may not be particularly well suited for fishery management in the context of monitoring and performance. Use of aggregated measures of ecosystem performance may be a better approach in the situation where data are limited.

Implementation

The details of how to implement an EBM approach were discussed at length. Implementation details generally fell into two categories: science and

management.

Science

The importance of choosing appropriate attributes to index was discussed and several candidate categories of metrics were suggested. The group felt that some measure of biodiversity, system level production, species interactions, benefits, and critical trophic linkages would be useful. We need to find and develop indicators of ecosystem properties we can predict and control. A large number of data needs were also identified, including feeding studies, bycatch data, measures of production (e.g., growth, production: biomass ratios, bioenergetics, natural mortality, catch, and recruitment), and comprehensive abundance indices from research surveys. In addition, spatial and temporal distribution information, environmental data, and socio-economic data were considered important. The data requirements of ecosystem science are challenging, even daunting, and technological innovations may be needed to provide sufficient data. It may also be necessary to look beyond the resources of the agency to form linkages and partnerships with other colleagues and disciplines, because it is unlikely that NOAA/NMFS can increase its own resources by an order of magnitude as will probably be required. Approaches that allow for synthesis and comparison of information were considered to be very important. The group felt that fisheries systems provide a unique opportunity for studying applied ecology and that sufficient resources should be provided to accomplish this task. Using simulation to study critical processes, fisheries impacts, model performance, organizational levels, and single-species and multispecies perspectives was considered of primary importance. Comparative ecosystem studies would also add significantly to our ability to analyze and measure system responses. Useful approaches might include mass balance models, simulation studies, research surveys, and ecosystem emergent properties and patterns.

Management

The management regime necessary for the implementation of ecosystem approaches was discussed. The consensus of the group was that there is an important need for a set of clear guidelines for implementing EBM (e.g., similar to the guidelines for the Magnuson Act's 10 National Standards). It was also considered that the ecosystem implications for advice based on individual stocks should be provided in Fishery Management Plans (FMPs), and that the associated environmental impact statements (EISs) should place more emphasis on processes (e.g., the implications of bycatch) rather than simply providing an inventory of associated species. The group began to investigate the possibility of using a Fishery Ecosystem Plan (FEP) as a document to provide guidance and clarification for FMPs. It was agreed that describing ecosystem attributes, interactions, and secondary effects of fishing in an FEP would be very helpful. Providing clear and unambiguous guidelines and links to the regulatory and governance process was also considered important. FEPs should be used to document potential ecosystem interactions and processes, and to provide guidance for formulating individual FMPs. The group felt that it should be recognized that an FEP is a dynamic document and the need to incorporate new science, historical information, and changes in system status are vital to the processes. An FEP should be used to set the priorities between FMPs. It could also be used to inventory and address issues from stakeholders such as the fishing industry or NGOs.

Problems and Limitations

The group recognized that several major problems and limitations will be important to consider when implementing EBM. First, it may require greatly enhanced monitoring with associated increased costs. Depending on the goals and objectives, these costs

may be very large or even prohibitive. Second, there will necessarily be many competiting objectives in an EBM plan. This will make implementation a challenging task. Third, the same level of theoretical basis analogous to the single-species situation may be lacking for ecosystem concepts. Fourth, economic analyses are likely to be far more complicated; for example, it will be difficult to determine net benefits if several objectives such as yield and biodiversity are being assessed simultaneously. Fifth, there will continue to be many competing factors such as protected species, habitat, MPA's, and conflicting legislation such as MMPA to reconcile. Overall, the group recognized that complex EBM approaches may be problematic due to the great demands on budgets and FTEs that would be required.

SUBTHEME II: BIOLOGICAL AND TECHNOLOGICAL INTERACTIONS

Discussion Leaders and Rapporteurs: ***Pat Livingston (AFSC), Alec MacCall (SWFSC), Paul Spencer (AFSC), and Grant Thompson (AFSC)***

Biological and technological interactions are extremely important to fisheries science and management, yet they are usually addressed as occasional research projects rather than forming a routine part of the stock assessment process.

Why Multispecies Models Are Not Used More Often for Management Advice

There are a number of reasons why multispecies models are not used more frequently for management purposes. First and foremost, for many systems multispecies models simply do not exist. There is often a vicious cycle with respect to the justification for multispecies models: stock assessments do not use multispecies models because they do not exist; the models do not exist due to a lack of necessary data; and sometimes the data do not exist because multispecies data collection has not been a priority of management.

Second, in situations where both multispecies and single-species models exist, the two approaches may lead to conflicting advice. Because advice obtained from single-species models has been the norm in most cases, contrasting advice obtained from multispecies models may find difficulty gaining acceptance.

Third, multispecies models are limited by the current understanding (or misunderstanding) of trophic links and ecological principles, and are often constructed to characterize dynamics in a qualitative manner rather than providing quantitative assessment advice. Some examples in which qualitative understanding of an ecological principle was defective to the extent that advice based on this understanding would not have had the intended results include clearing Oregon coastal streams of woody debris, and the proposed intense fishing of anchovy in the 1960s to facilitate the return of the California sardine. Currently there is debate as to whether Alaskan pollock should be fished more intensely (to reduce losses due to cannibalism) or less intensely (to enhance forage for protected species), or whether increased fishing pressure on elasmobranchs would enhance the abundance of more marketable species on Georges Bank.

Fourth, inclusion of multispecies interactions in stock assessment models can make the prospects of rebuilding overfished stocks appear more pessimistic than if such interactions are ignored. It may be difficult

for models that paint a bleaker picture of the future to gain acceptance.

Fifth, bigger models are not always better. For example, it had been thought by some that the recovery of Georges Bank cod and haddock was being restricted by spiny dogfish predation, thus suggesting that models used to assess cod and haddock should be expanded to include interactions with spiny dogfish. However, examination of numerous dogfish stomachs later revealed that they are not an effective predator of these fish. Furthermore, dogfish are one of the few predators that consume ctenophores which themselves are potentially important predators on cod and haddock larvae.

Sixth, some people are concerned (rightly or wrongly) that the advice generated by multispecies models carries a greater risk of being highly misleading than does the advice generated by single-species models. It is important that this concern be addressed. One approach is to construct a simulation model as follows: (i) begin with a multispecies simulation model, (ii) simulate stock and fishery dynamics over time, generating simulated data along the way, (iii) use both single and multispecies assessment models to estimate parameters from the simulated data, (iv) use the parameters estimated from the single and multispecies assessment models to generate management advice, and (v) compare the management advice from the single and multispecies assessment models with the management advice obtained from the (true) multispecies simulation model.

Issues Involving Technological Interactions

Technological interactions were recognized as one of the main constraints on maximizing ecosystem yields. Differences in catchabilities of two species with equal productivity can cause overharvest of one species. Similarly, differences in productivity of species in mixed stock fisheries serve to constrain achievable ecosystem yields. However, these interactions were perceived by the group to be more manageable than biological interactions. An example was discussed wherein a cooperative approach to bycatch pooling among vessels helped greatly in providing incentives to keep bycatch low.

In order to parameterize most existing ecosystem or multispecies models, estimates of total mortality are required. Observers are necessary for such estimates, but not sufficient, because such estimates should include mortality that does not appear as catch (i.e., animals killed but not retained by the gear).

Discard mortality is one component of total mortality that is often difficult to estimate. Some regions do not have sufficient observer coverage to quantify discards, in which case careful consideration should be given to the manner in which observers are allocated. For example, it might be appropriate to give priority to fisheries that are perceived to have the largest or hardest-to-estimate bycatch rates. However, uneven observer coverage can put observed fisheries at a competitive disadvantage relative to other fisheries. Given that universal coverage is unlikely to be economically feasible, a "statistical design" approach was suggested as being the most appropriate, with the understanding that placement of observers within strata should be truly random. It might also be appropriate to rotate observer coverage across fisheries to ensure that no fishery goes completely unmonitored.

It is not clear that the current allocation of observer coverage among fisheries is rational. For example, some fisheries with ESA bycatch issues are not monitored while some fisheries with low bycatch rates are. There are also institutional issues involving implementation of observer programs. Who pays for programs in fisheries with low profit margins? Allocating TAC to get observers was mentioned as one possible solution. Some fraction of rents from the resource could go to managing the system. This might mean in the long term that the total level of exploitation would have to be lower (i.e., it might be necessary to maintain a larger biomass in order to realize a profit margin sufficient to pay for the observing system.)

Alternatively, it might be appropriate for observer program funding to come from a broader base than the particular fishery being observed. For example, multi-species concerns may require a national perspective on the fishery observing system. Several examples of how existing observer programs have been funded were mentioned. International contributions go to the 100% observer coverage obtained in the Southern Ocean. In British Columbia, the industry owns (and operates) the observing system. In the Alaska groundfish fishery, industry pays for the observers themselves, while observer training and other program functions are paid for by the federal government. Federal mandates for protection of marine mammals might imply at least some federal support of the observing system. It was also mentioned that different management entities have different and possibly competing goals and that integrating those goals might be difficult. (e.g., restrictions on halibut bycatch, which affects Pacific coast groundfish fisheries).

Objectives For Multispecies Management

There are a number of possible objectives for multispecies management, including but not limited to the following:

- Optimize the mix of species/guilds
- Optimize the mix of economic benefits
- Maximize stability of the ecosystem
- Maximize stability of economic benefits
- Maximize aggregate sustainable yield
- Maximize aggregate (either sustainable or discounted) value or rent

An aggregate MSY could be defined as "the largest sustainable catch of all species" or "the largest sustainable catch of all target species" and could be calculated on the basis of some multi-species or ecosystem model, giving a figure that would likely be different from a summation of single-species MSY values. For example, suppose a multi-species model containing m target species numbered 1 through m and an arbitrary number of non-target species. Suppose further that a distinct target fishery is associated with each of the target species (this assumption could easily be relaxed, but it helps to simplify notation), and that each such target fishery may impose bycatch mortality on any other target or non-target species. In the deterministic case, such a model will have an equilibrium state defined by the vector of fishing mortality rates associated with the m target fisheries. Let the vector of fishing mortality rates that maximizes the sum of the target species equilibrium yields be designated F'. Next, for each target species i, consider the target fishing mortality rate F_i'' that maximizes the equilibrium yield of that species conditional on all other target fishing mortality rates being set equal to their respective $F_{j \neq i}'$ values. The following inequalities should then generally obtain:

$$\sum_{i=1}^{m} Y_i(F_1', \ldots, F_{i-1}', F_i'', F_{i+1}', \ldots, F_m') \geq$$

$$\sum_{i=1}^{m} Y_i(F_1', \ldots, F_m') \geq$$

$$\sum_{i=1}^{m} Y_i(F_1'', \ldots, F_m'')$$

In the first sum, the yield for each target species is calculated as though the respective target fishery (and *only* that target fishery) gets to "cheat" by trying to maximize the yield from its target species at the possible expense of yields from other target species. This sum should typically be no less than the second sum, where yields are maximized jointly. The second sum, in turn, should typically be no less than the third sum, where the individual "cheater" fishing mortality rates are applied jointly (rather than one at a time, as in the first sum). Note that the first sum could never be achieved in practice, except in the limiting case where it is equal to the second sum.

The aggregate MSY is a useful thing to know, but maximization of aggregate equilibrium yield may not be the best management objective. For example, maximizing aggregate equilibrium yield may involve fishing predator species to very low levels in order to obtain high yields of lower trophic level species.

Choosing a particular objective function will likely involve allocating harvest between fishermen targeting on different species. This may not be an easy choice to make, but it is not necessarily any more difficult than current "routine" choices involving allocation of single-species harvests between sectors of a fishery.

Depending on objectives, ecosystem based management (EBM) may have major impacts on existing fishery and industry structure, such as substantial reallocations of TACs due to changes in intensity, targets, and mixes of gear. Under some scenarios, this could also require a reduction in the number of participants simply to allow more effective tracking of fishery harvest and performance. It is likely that some potential ecosystem goals will conflict with values held by one or more segments of society, and that resolution of such conflicts will be a major challenge in the years to come.

The following proposal for evaluating multiple objectives using multispecies models was put forward in the hope of prompting further discussion and study:

Suppose that n non-target species numbered m+1 through m+n are added to the model described previously (in the context of defining an aggregate MSY). As before, such a model will have (in the deterministic case) an equilibrium state defined by the vector of fishing mortality rates associated with the m target fisheries. This equilibrium state can be viewed in terms of equilibrium yields, equilibrium biomasses, or other equilibrium measure. A natural question to consider is, "What would the optimal equilibrium state in such a system look like?"

A possible answer might arise by comparing two of the statutes that currently govern management of living marine resources in the EEZ: the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) and the Marine Mammal Protection Act (MMPA). Viewed in the simplest terms, the main objective of the MSFCMA might be perceived as maximization of equilibrium yields from target species, while the main objective of the MMPA might be perceived as maximization of equilibrium biomass from non-target species (specifically, marine mammals). Of course, it will typically be impossible to achieve both of these objectives simultaneously. Therefore, it might be reasonable to consider an objective function that consists of a weighted sum of these two:

$$\alpha \sum_{i=1}^{m} \frac{\ln(Y_i(F_1,\ldots,F_m))}{m} + (1-\alpha) \sum_{j=m+1}^{m+n} \frac{\ln(B_j(F_1,\ldots,F_m))}{n},$$

where *alpha* is a weighting factor between zero and unity (with a value of 0.5 implying equal weighting), Y_i is the equilibrium yield of target species i, F_i is the target fishing mortality rate associated with target species i, and B_j is the equilibrium biomass of non-target species j.

Some of the advantages offered by the above objective function are:

(i) Use of logarithms has the advantages of rendering any solution involving extinction inadmissible and eliminating the need to scale individual species yields or biomasses relative to their respective maxima (i.e., such scaling could be undertaken for aesthetic purposes, but would have no impact on the solution). In the context of single-species models involving parameter uncertainty, use of a logarithmic utility function has been suggested as a formal means of incorporating risk aversion into management advice.

(ii) Scaling each of the two summations relative to the number of species in the respective category (target, non-target) has the advantage of making the expected value of each summation independent of the number of species in the respective category (without such scaling, the optimal overall level of exploitation might be expected to increase every time a new target species is added to the

model and to decrease every time a new non-target species is added to the model). The parameter *alpha* therefore has the same interpretation across models, thus enabling a general (as opposed to a model specific) evaluation of alternative *alpha* values.

Of course, the above objective function is only one possible candidate. It could be modified in many ways, such as weighting individual species yields by their respective prices (or other measure of economic value), including target as well as non-target species in the biomass summation, or including additional summation terms (e.g., a penalty function designed to minimize fishing effort); or it could be replaced by an entirely different function.

It is not immediately clear how a management recommendation based on the above (or any analogous) objective function might interface with existing constraints imposed by the National Standard Guidelines. For example, the Guidelines' requirements pertaining to status determination criteria were formulated largely in a single-species context, and it is not obvious how they would best be interpreted in a multispecies context. However, this should not discourage research on objective functions such as the one suggested here.

A largely unresolved problem in fishery management is the appropriate rate of transition from the status quo to the optimal management regime. This problem will likely be no less difficult in the case of multispecies models than in the case of single-species models. In either case, though, if the rate of transition is slow enough, consideration might be given to research that focuses simply on the *direction* of needed change as an alternative to research that focuses on the optimal long-term management regime itself.

SUBTHEME III: SHORT AND LONG-TERM CLIMATE AND OTHER ENVIRONMENTAL/OCEANOGRAPHIC EFFECTS

Discussion Leaders and Rapporteurs: ***Anne Hollowed (AFSC) and Rick Methot (NWFSC)***

Members of this discussion group were charged with identifying the pros and cons of including climate and other environmental information in analysis of population dynamics. The Ecosystem Principles Advisory Panel (1999) recommended that Fisheries Management Councils develop Fisheries Ecosystem Plans (FEPs) containing three elements:

- A clear description and understanding of the fundamental physical, biological, and human/ institutional context of ecosystems within which fisheries are managed.
- Direction on how that information should be used in the context of FMP's.
- Policies by which management options would be implemented.

Our discussion group explored potential activities which would include climate and ocean variability information in such FEPs.

General Approach

The group recognized that marine organisms show a broad range of responses to spatial and temporal changes in the environment. The nature and intensity of the response stems from the specific life history of the organism and how directly coupled a life history process is to climate forcing (Steele and Henderson 1984, Francis *et al.* 1998).

The challenge facing our discussion group was to identify the steps necessary to utilize the research findings of fisheries oceanographic research programs in annual stock assessment advice. Our approach was to discuss three trigger questions.

- What are the appropriate time scales for improving prediction of future productivity of species?
- When do we know that a persistent environmental change has occurred?
- How do we incorporate these changes in management oriented thresholds such as optimal harvest policies and rebuilding depleted stocks?

Time Scales

In stock projections, recruitment is often modeled by drawing from a distribution that approximates observed recruitment, or by assuming a relationship between spawners and recruits with some error term. These assumptions imply that environmental conditions will be similar over past and projected time periods, with an implied focus on random interannual effects. Retrospective analysis of recruitment patterns of several marine fish suggests that decadal scale patterns in recruitment have a strong effect on fish populations. Decadal scale shifts in ocean conditions may influence the reproductive potential of the stock that would change the recommended harvest policy (e.g., recommended fishing mortality rate). Interannual variations in ocean conditions may modify recruitment projections that change short-term harvest recommendation (e.g., the ABC for next year).

Most fisheries management is based upon the expectation of quasi-equilibrium states found in most temperate systems. However, sudden basin-wide shifts in atmospheric forcing leading to shifts in ocean conditions have been observed in the North Pacific (Mantua *et al.* 1997, Overland *et al.* 1999). These shifts in ocean conditions appear to impact marine

production (Francis *et al.* 1998, Roemmich and McGowan 1995). Likewise, Planque and Taylor (1998) found strong correlation between plankton abundance and two modes of climate variability in the North Atlantic: the latitudinal shifts of the north wall of the Gulf Stream and the North Atlantic Oscillation. It appears that decadal scale shifts in tropical systems are not as evident.

The MSFCMA National Standard 1 Guidelines state that, "*if environmental changes affect the long-term productive capacity of the stock or stock complex, one or more components of the status determination criteria must be re-specified*". However, determination of such a change is difficult, so assessment scientists risk making one of several potentially erroneous decisions. For example, it could be assumed that the stock is in a low productivity regime when it is in fact in a high productivity regime but depleted due to overfishing. The reverse is also possible. Assuming a regime of high productivity when it is actually low means that a biomass-based rebuilding target may be impossible to reach in the near future; assuming a regime of low productivity when it is actually high means that a biomass-based rebuilding target will be relatively easy to attain but will be sub-optimal. When modeling the potential linkages between climate and population dynamics, assessment scientists should consider how climate affects the slope at the origin (r) and the carrying capacity (K) (Parma and Deriso 1989, Walters and Parma 1995). The harvest policy could be quite different depending on the factors influenced by ocean conditions. For example, if climate reduced the carrying capacity, MSY would occur at similar or lower spawner stock levels (Figure 2), but the optimum harvest rate could be similar. In contrast, if climate reduced stock productivity, then MSY would occur at higher spawning biomass levels (Figure 3) which could only be maintained through a lower harvest rate. Determining the exact relationship between recruitment and spawner abundance is difficult, especially because information on recruitment and spawners are rarely based on direct data. Recent enhancements to assessment models enable estimation of the stock-recruitment relationship within the assessment model, thus allowing better accommodation of the variability in the estimated recruitment and spawner information.

Detecting Environmental Change

The challenge facing fisheries scientists is to identify the leading indicators of decadal scale variability, and to identify the processes that would differentiate between shifts in carrying capacity and shifts in production. With the types of information available today, we expect that it will be much easier to detect changes in the physical environment than to determine how these changes affect fish stocks.

The different types and temporal scales of ocean influences on fish stocks confounds determination of general patterns. Ocean conditions influence production (year class strength), spawning distributions, and life history rate parameters (growth, maturation and natural mortality); however, these influences are seldom directly incorporated into stock assessment models in a way that will allow forecasting. Temporal patterns of production can vary between stocks (Caddy and Gulland 1983, Spencer and Collie 1997). For example, mean recruitment may change for some stocks and the frequency or magnitude of strong year classes may vary in others. In cases where the stock is composed of multiple year classes with delayed recruitment to the fishable stock, these processes may result in only gradual changes in biomass and delayed detection of such changes.

Tracking historical or current shifts in ocean forcing will assist assessment scientists to correctly interpret their analyses. For example, several authors have identified apparent relationships between selected environmental factors and recruitment, only to see these relationships dissolve with the addition of new data (Drinkwater and Myers 1987, Myers 1998). The failure of such analyses (typically correlative relationships) may be because the underlying models are overly simplistic or erroneous. Alternatively, the response of marine fish may differ if the ocean system

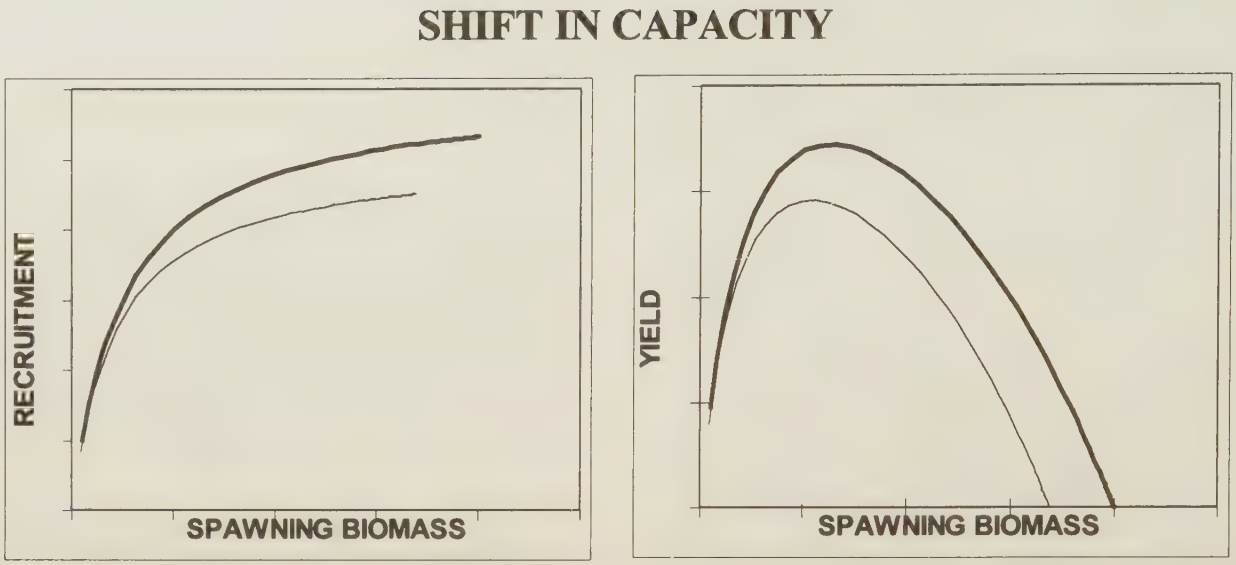

Figure 2. Effects of a shift in environmental carrying capacity on MSY and biomass.

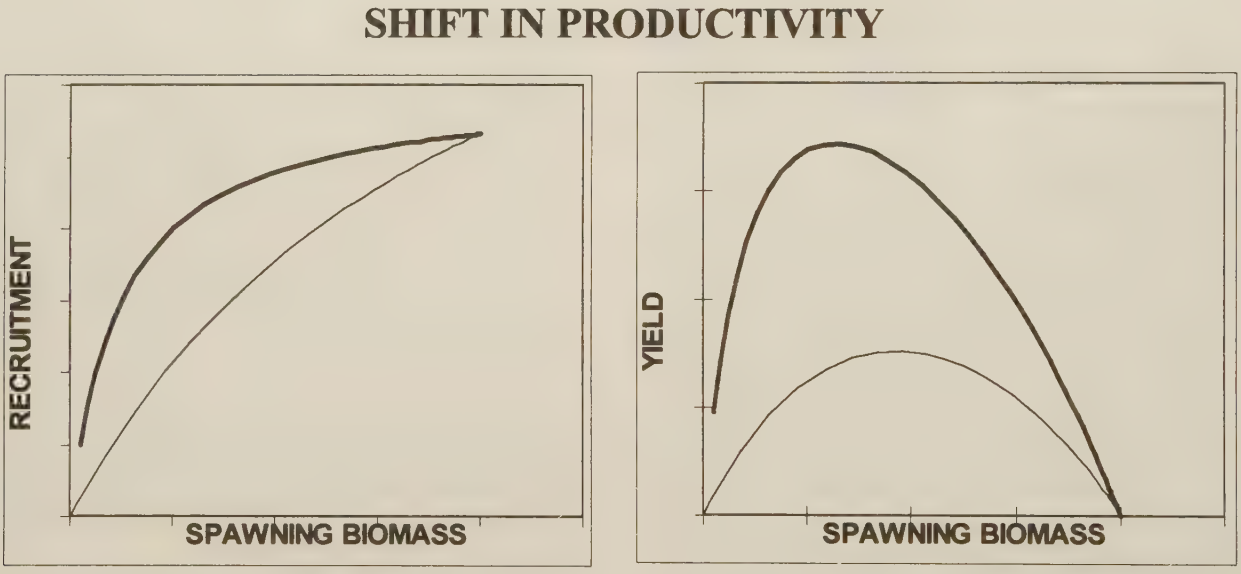

Figure 3. Effects of a shift in productivity on MSY and biomass.

Table 2. Process oriented interdisciplinary research programs linking oceanography to fisheries production. Primary funding agency identified in parenthesis.

Program	Abbreviation	Target Species	Location
California Cooperative Oceanic Fisheries Investigations (SIO, CDFG, SWFSC)	CalCOFI	Small Pelagics	West Coast
Fisheries Oceanography Coordinated Investigations (AFSC, PMEL)	FOCI	Walleye pollock	Gulf of Alaska
Global Ecosystems Dynamics (COP, NSF)	GLOBEC	Atlantic cod and haddock	Georges Bank
Global Ecosystems Dynamics (COP, NSF)	GLOBEC	Pacific salmon	Northeast Pacific
South Atlantic Bight Recruitment Experiment (COP)	SABRE	Menhaden	South Atlantic Bight
Southeast Bering Sea Carrying Capacity (COP)	SEBSCC	Walleye pollock	SE Bering Sea Shelf

SIO - Scripps Institute of Oceanography, CDFG California Department of Fish and Game, SWFSC- Southwest Fisheries Science Center, AFSC - Alaska Fisheries Science Center, PMEL - Pacific Marine Environmental Laboratory, COP - Coastal Ocean Program, NSF - National Science Foundation.

shifts. If the latter explanation is accurate, partitioning the data into temporal groups associated with consistent ocean conditions may help to elucidate key processes underlying fish production.

Understanding mechanisms underlying shifts in marine production at shorter time scales should allow assessment scientists to more accurately reconstruct the history of production. Large interdisciplinary research teams have been instrumental in providing mechanistic information needed to develop functional relationships between climate and/or ocean forcing on marine production (Table 2). Several research programs have provided conceptual models of processes underlying recruitment variability that could form the basis for annual recruitment forecasts. In some cases (e.g., GOA pollock, northern anchovy, Pacific sardine, Georges Bank cod and haddock, and selected Pacific salmon stocks), mechanisms are sufficiently understood that it may be possible to formally incorporate environmental forcing into assessment models. Monitoring programs could be developed or enhanced to allow annual predictions of expected trends (short- or long-term) in fish production.

Integration of information from many species and systems can facilitate understanding of the underlying processes and timing of basin-scale shifts. The Fisheries And The Environment (FATE) initiative is designed to provide a compilation of biological and physical from locations throughout the North Pacific, Bering Sea and North Atlantic to improve our ability to detect shifts in climate forcing or marine production. This initiative will encourage assessment scientists to look for common signals across many species in a system to get dominant patterns in fish production. The FATE initiative will also encourage interdisciplinary participation in production of annual reports on the state of the three regions that would be submitted to Fishery Management Councils at the time of stock assessment deliberations. This program may contribute towards formalizing an ECOWATCH monitoring program as suggested by the Ecosystem Principles Advisory Panel.

Harvest Strategies

If environmental influences have been detected, assessment scientists should consider how this information should be used in formulating management advice. Key questions include:

- How does the interaction between generation time and dominant period of climate forcing affect the optimal long-term harvest policy?

- Which environmental indices are best used as input to biological models? Should these be data driven (e.g., mean temperature), or syntheses of physical information into an index (like ENSO or PDO)? What are the mechanisms for obtaining the best and most timely physical information?

Retrospective analyses could be performed to evaluate the utility of adding information to assessment models. Parma and Deriso (1989) and Walters and Parma (1995) provide examples of methods for evaluating the cost of incorporating shifts in environmental variation in harvest strategies. Megrey *et al.* (1996) and Beamish and McFarlane (1999) provide examples of methods for incorporating environmental data into short term yield recommendations.

Group discussions highlighted the following research questions:

- Do current harvest guidelines provide enough insurance to allow the stock to weather a prolonged period of low productivity?

- Many stocks become more productive at reduced stock sizes because of reduced competition leading to accelerated growth and maturation (e.g., Atlantic cod). How do we reconcile this expectation with a reduced production scenario?

- The environment may influence the distribution and spatial extent of suitable spawning habitat. For example, do fishery-induced reductions in stock size influence the probability of colonizing a spawning location in a new regime?

- Should regime shifts be invoked if they are not expected to persist as long as a generation time?

- How do we build environmental information into estimates of the minimum stock size threshold (MSST) and/or the optimal fishing mortality rate (F_{opt})? How does this vary for long-lived versus short-lived species? Can the harvest policy just be reactive to changing biomass, or can we be proactive (regime shift) and adjust F based upon expected changes?

SUBTHEME IV: SECONDARY EFFECTS OF FISHING

Discussion Leaders and Rapporteurs: ***Waldo Wakefield (NWFSC), Michael Fogarty (NEFSC), Ian Butler (NWFSC), and Jim Ianelli (AFSC)***

The discussion group began by defining areas of particular importance for the ensuing discussions. The principal themes selected revolved around the direct and indirect effects of fishing and on their implications for the development of management strategies. The list of potential effects identified by the group for consideration included:

- Gear impacts on habitat
- Bycatch and discards (dead and alive)
- Effect on trophic structure of the removal of predators or prey
- Modification of fish behavior by fishing activities (e.g., disruption of spawning)
- Ghost fishing by lost gear
- Bio-geochemical effects of seafloor disturbance, changes in nutrient cycling, and sediment transport
- Economic influences and decisions

Time did not permit an exploration of this last topic during the sessions. The group also discussed potential management responses to these secondary effects of fishing. Among the themes considered under potential management responses were:

- Management tools available for ecosystem impacts of fishing (with special emphasis on marine protected areas)
- Biological reference points and the implications of habitat loss and disturbance
- Potential solutions to bycatch problems

Gear Impacts on Habitat

A major focal point of the discussions was the general issue of gear impacts on habitat. This topic has received increasing attention in deliberations on the ecosystem effects of fishing. It was noted by the group that the impacts of harvesting gear and practices must be evaluated in the context of natural rates of disturbance which can be expected to vary substantially according to depth, substrate type and the biological communities in an area, and according to the physical forcing processes operating in these areas (e.g., wind fields and tides). Areas with low natural rates of disturbance and higher levels of structural complexity due to geological or biogenic structures are more vulnerable to long-term impacts of disturbance by fishing gear. Experimental evidence of the effects of trawling on the productivity of exploited systems has been obtained in studies on the northwest continental shelf of Australia where removal of macrobenthos by trawling adversely affected the abundance of fish species that utilized the biological structures for shelter. However, species with a preference for habitats with low structural complexity increased in abundance in the trawled areas.

Given that it is commonplace to define acceptable levels of removal for target fish and invertebrate species, as well as protected species such as marine mammals and turtles, should there also be "acceptable levels of mortality that can be imposed on benthic organisms" by bottom gears? Defining biological reference points for benthic communities would be challenging for several reasons. Most importantly, it was recognized by the group that expertise in benthic ecology and the taxonomy of benthic organisms has eroded, both in general and specifically within NMFS. In recognition of the likely increasing importance of this issue, the group believed that there needs to be a renewed emphasis within NMFS on benthic ecology and benthic species identification.

Bycatch and Discards

It is now widely appreciated that the twin problems of incidental bycatch and discarding (including highgrading) pose a significant threat to marine populations. The level of discarded fish can often approach 25% overall of the landed catch, and in some fisheries (e.g., shrimp) it can be considerably higher. Adequate documentation of the levels of bycatch and discarding is often lacking. These removals (and the age or size structure of the discards) must be accounted for in stock assessments to fully evaluate the impacts of harvesting on the population(s). Discarding can also change fundamental pathways of energy flow in systems by making available to some components protein that would not otherwise be accessible (e.g., sea birds that follow fishing vessels to feed on unwanted catch discarded at sea). However, the pros and cons of selective removal of a few components of a biological community compared to removals (landings plus discards) of all species more or less in proportion to relative abundance have not been fully investigated.

Trophic Structure Effects

Large-scale changes in fish community structure have been observed in many systems as harvesting has differentially affected the species composition. The decline of some species targeted by fishing has been followed in many instances by increases in other, less intensively exploited species. It has been inferred that these shifts in species composition are mediated by trophic interactions. Sometimes reductions in competitors or predators can result in increases in the abundance of interacting species which can be detrimental to the ecosystem overall (e.g., in coral reef systems, removal of large predators may be followed by substantial increases in parrotfish which destroy the reefs). Particularly strong changes in the system structure on the Northeast Continental Shelf have been attributed to this type of mechanism. For example, as commercially important groundfish declined in abundance, the biomass of small elasmobranchs (dogfish and skates) has increased. The system is thought to be tightly bound from an energetic viewpoint and therefore declines in the abundance of some species may make increased resources available to others. Small pelagic fish (particularly herring and mackerel) increased dramatically in abundance as fishing pressure declined and as piscivorus fish biomass declined.

Modification of Fish Behavior

Many species of fish form aggregations during breeding periods and these groups are highly vulnerable to fishing. Their high densities usually result in high catch per unit of effort which makes them particularly attractive to fishers. In addition to the direct removal of breeders, in some cases prior to spawning, there may be disruption and dispersal of the aggregations themselves in response to the disturbance which may reduce overall spawning success. Fisheries that target spawning aggregations may, however, entail lower levels of bycatch and discard.

In other instances, the effects of harvesting in truncating the age or size distribution has been linked to a loss of fish school members with learned behaviors regarding spawning and feeding sites.

Ghost Fishing

Lost fishing gear that continues to capture individuals is a significant problem in many trap-based fisheries and in gillnet fisheries. The true magnitude of lost fishing gear is often unknown but has been estimated to be high in fisheries for lobster on the east coast and crab fisheries on the west coast. Unbaited traps can still continue to attract individuals seeking shelter in the structure afforded by the trap. Gill nets can continue to entangle target and non-target species. Although solutions to some of these problems have been identified (e.g., the use of escape vents and degradable links in traps), others have not been adequately addressed (e.g., the gillnet problem).

Biogeochemical Effects

Alterations to sedimentary sea floor environments by mobile fishing gear (trawls and dredges) is recognized as a major factor in the ecology of systems such as the Mid-Atlantic Bight and the Gulf of Maine. Large scale resuspension and redistribution of sediments have been estimated in such systems with important implications for fundamental ecological processes such as biogeochemical cycles and nutrient budgets.

Management Implications

The group took as a basic premise that fishing practices may impact marine communities in a way that requires alteration of biological reference points and that this needs to be taken into account in interpreting historical data and in projecting stock recovery patterns. For example, if harvesting removes fish and simultaneously degrades habitat, a change in the shape of the production function can be expected (relative to the case where harvesting simply removes individuals). The overall level of maximum sustainable yield and the fishing effort level resulting in MSY can be much lower when fishing jointly impacts abundance and carrying capacity of the environment.

It was agreed that if harvesting does affect the environment in this way, then harvesting strategies and biological reference points must be adjusted accordingly. However, it was also recognized by the group that the effects of harvesting on carrying capacity or overall productivity are poorly known in general at this time. It was further recognized that separating the effects of harvesting from other (natural) environmental changes can be exceedingly difficult.

Considerable attention was given to the potential for Marine Protected Areas as research and management tools that can potentially address both the direct and indirect effects of fishing on marine populations and communities. It was recognized by the group that considerable uncertainties remain in the probable performance of marine reserves, especially those aspects related to the dispersal characteristics of the populations. The current interest in MPAs as a conservation tool has not fully appreciated the issues surrounding this source of uncertainty. The group agreed that MPAs are needed to fully understand the secondary effects of fishing in some form of experimental approach to the problem.

It was thought to be useful to set aside large areas about which little is known as a precautionary measure. Particular emphasis was given to deep water areas where many species are very long lived and slow growing with low productivity. The group favored a blanket recommendation to prohibit harvesting at depths greater than 800-1000 m as a precautionary measure, making exception for specific fisheries where stock and ecological sustainability can be demonstrated. It was also recognized that vulnerable systems such as coral reefs have benefitted substantially by the establishment of marine reserves.

In cases were the species and populations of interest are more mobile in the juvenile and adult stages, the benefits of MPAs as ways of controlling fishing mortality are less clear (although the potential benefits in terms of reductions in secondary effects of fishing may well remain). It was recognized that in such cases it is particularly important to maintain other forms of control on fishing pressure.

The groups discussed general criteria for identifying candidate areas and habitats for MPAs including:

- Ecological significance
- Sensitivity
- Rarity
- Extent already affected

The importance of MPAs as designated research areas was highlighted in the discussions. It was felt to be important that the MPAs be designated as no take zones and that only non-extractive uses be permitted. The role of MPAs as a hedge against management uncertainty was discussed and it was generally agreed that MPAs can play an important role in this regard.

SUMMARY OF WORKSHOP CONCLUSIONS & RECOMMENDATIONS

Science/Research

- Single-species approaches should continue to be the primary focus of assessments and management advice for the foreseeable future, particularly for the short term planning horizons typical of most fishery management systems, but multispecies and ecosystem level models will be an important source of ancillary advice for ecosystem-based management (EBM)

- There are several metrics available for indexing the status of ecosystems at several hierarchical levels, but a thorough analysis of the performance of these metrics is needed

- Despite confusion over what constitutes EBM, the concept of MSY has meaning in a multispecies context; it can be defined as "the largest sustainable aggregate catch of all species (or all targeted species)"

- Aggregate MSYs are likely to be less than the sum of single-species MSY values

- Since maximization of the aggregate catch may involve fishing predator species to very low levels in order to obtain high yields of lower trophic level species, other objective functions may be more sensible. For example, an objective function that takes into account the competing objectives of maximizing aggregate economic yield and maximizing biomass of non-target species could be considered

- Economic analyses are also needed to compare the desirability of alternative ecosystem states

- At the least, metrics are needed for monitoring biodiversity, system level production, species interactions, critical trophic linkages and habitat characteristics such as physical and biological structural complexity, physical vulnerability, and habitat diversity

- The NSAW recommends that a workshop be conducted to explore the utility of metrics for monitoring and measuring ecosystem properties

- Simulation studies should be conducted to identify key ecosystem processes and data gaps, examine fisheries impacts, and compare performances of alternative models (e.g., single-species versus multispecies models, and models with and without environmental forcing)

- Multispecies and ecosystem models have undergone considerable evolution over the last quarter century, and substantial progress has been achieved

- In contrast to the all encompassing ecosystem models that were the goal of the International Biological Program and similar endeavors, current multispecies and ecosystem models tend to be more "tactical" in nature, that is, designed to address specific questions rather than to synthesize the totality of existing knowledge

- Multispecies and ecosystem models are rarely used for management purposes; more research and communication is needed to further develop such models and to further develop confidence in them

- Ocean conditions influence production, spawning distributions, and life history parameters, yet these influences are rarely incorporated into

stock assessment models, primarily because there are few cases where environmental forcing mechanisms are sufficiently understood

- It is important to consider time scales when making predictions about future stock size; for example, although actual recruitment varies on an annual time scale, mean productivity is more likely to vary on decadal time scale; more research is needed to develop appropriate methods for forecasting recruitment at various time scales

- Indicators of decadal scale variability need to be identified

- It is important to determine whether shifts in ocean conditions are more likely to affect carrying capacity or productivity (or both)

- A variety of species with long data series and good data should be examined for potential environmental effects on survival ratios (R/S, the ratio of recruits to the spawning biomass that produced them) and absolute recruitment; for example, selected salmon stocks, Pacific halibut, menhaden, Pacific cod, haddock, and Pacific sardine

- A basic research question that needs to be addressed is how fishing alters the overall productivity of a system in light of both its effects on target species and the secondary effects of fishing such as bycatch and discards of non-target species, gear impacts on habitat, effects on trophic structure of removals of predators or prey, potential modification of fish behavior by fishing activities (e.g., disruption of spawning), ghost fishing by lost gear, and changes in geochemical cycles, nutrient cycles and sedimentation

- Expansion to EBM is likely to require renewed emphasis on certain disciplines in which NMFS currently has very few or no staff; e.g., benthic taxonomy and benthic ecology

- The effects of discarding of undersized or unwanted species need to be taken into account, not just in single-species stock assessments of the discarded species but also in terms of changes to the fundamental pathways of energy flow in biological communities

- Since EBM may require moving toward more selective gears, NMFS should renew efforts to encourage the industry to develop more environmentally-friendly fishing gears, including off-bottom gear types

Management

- In most cases, fisheries failures have been the result of a general failure in fisheries management, not the science or the advice

- It is important to clearly define goals and objectives for EBM

- Implementation of EBM will be difficult due to the large number of potentially-conflicting objectives; for example, providing high yields for commercial fishers, maximizing the aggregate sustainable yield or value, providing large and abundant fish for recreational fishers, optimizing the mix of economic benefits, maintaining high biodiversity and species diversity, and protection of rare, endangered or protected species

- Alternative multispecies or ecosystem objective functions should be developed and evaluated

- Guidelines for implementing EBM, similar in terms of the level of detail to the NMFS National Standard guidelines, are also required

- Fisheries Ecosystem Plans (FEPs) should be developed as umbrellas to the current system of FMPs, clearly linking those FMPs that pertain to the same marine ecosystem

- FEPs should at the least contain descriptions of what is known about ecosystem attributes, species interactions, and secondary effects of fishing

- Methods for incorporating environmental influences into management advice need to be developed; for example, how do/should potential shifts in ocean conditions affect optimal long-term harvest policies?

- Extension of current management systems to EBM may require consideration of mortality rates on components of ecosystems other than harvested species and protected species; e.g., the benthic community

- Degradation of habitat by fishing gear may impact marine communities in ways that require alteration of biological reference points, and this should feed back into the management process to result in reduced target fishing mortality levels or gear restrictions. Both the overall level of MSY and the fishing effort associated with MSY can be much lower when fishing jointly impacts abundance and the carrying capacity of the environment

- Marine Protected Areas (MPAs) should not be thought of only in the narrow context of providing some conservation benefit for harvested species; indeed, depending on the size of the MPA and the dispersal characteristics of the species of concern, they may provide little if any conservation benefit and therefore should not be used as a rationale for reducing other forms of control on fishing pressure

- More attention should be focused on the utility of marine protected areas (MPAs) as research and management tools that can potentially address several of the problems associated with both the direct and indirect effects of fishing on marine populations and communities

- In particular, more emphasis should be placed on the potential importance of MPAs as designated research areas where, for example, controlled experiments can be conducted to investigate secondary effects of fishing

- The shape, size and functioning of candidate MPAs needs careful consideration. Criteria for the identification of candidate MPAs may include habitat areas of particular concern (HAPCs), research areas, high diversity areas, areas for ecotourism , buffer areas, and representative areas. Such areas may or may not serve the purpose of increasing fisheries yields but in most cases they should aid in hedging against uncertainty

- NMFS should take a more proactive role in habitat management by, for example, setting aside potentially critical areas, even though information is lacking (e.g., low productivity deep water areas), or "hot spots" that have high diversity or unique species

Data

- There is an alarming lack of adequate baseline monitoring data for marine species (both target and associated) and marine habitat. However, it would be impossible for NMFS to conduct all of the necessary monitoring, especially with current resources, and even with substantially expanded resources (e.g., double the current level). There is a need to develop partnerships and other cooperative arrangements to collect and share data from comprehensive monitoring programs

- Depending on the actual goals and objectives, the costs of obtaining the data needed for full EBM may be substantial

- Lack of adequate data is likely to be more limiting than the ability to build multispecies and ecosystem models in furthering ecosystem science;

however, lack of adequate data should not preclude initiation of EBM

- Improved fishery observer programs and long-term, fishery-independent ecosystem monitoring are essential to tracking ecosystem changes and building predictive models

- Observer programs are essential for assessing the secondary effects of fishing such as effects on associated, non-target species caught as a result of technological interactions; observer programs should be expanded considerably

- Important data needs include feeding studies, by-catch data, comprehensive abundance indices from research surveys, information on spatial and temporal distribution, environmental data, and measures of production such as growth, production/biomass ratios, bioenergetics, natural mortality, catch and recruitment

- Socio-economic data are also severely lacking

- Enhancements are needed to inventory what is already known, and to expand mapping and monitoring of the physical and biological marine habitat and fish associations with these habitats

- The NSAW endorsed the concept of large interdisciplinary projects such as the Fisheries And The Environment (FATE) initiative and GLOBEC, and supported the idea of a monitoring program along the lines of the ECOWATCH program proposed by the Ecosystem Principles Advisory Panel.

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APPENDIX I: WORKSHOP AGENDA

6th NMFS National Stock Assessment Workshop (NSAW)

INCORPORATING ECOSYSTEM CONSIDERATIONS INTO STOCK ASSESSMENTS AND MANAGEMENT ADVICE

What are the pros and cons of going beyond single species??

March 28-30, 2000

Hosted by the Northwest Fisheries Science Center

Venue: Aljoya Conference Center
3920 N.E. 41st Street
Seattle, WA 98105

Steering Committee:
Pamela Mace (F/ST2 - HQ)
Ed Casillas (NWFSC - Seattle)
Rick Methot (NWFSC - Seattle)
Alec MacCall (SWFSC - Tiburon/Santa Cruz)
Bill Overholtz (NEFSC - Woods Hole)
Mike Prager (SEFSC - Beaufort)
Grant Thompson (AFSC - Seattle)

– *AGENDA* –

Tuesday 28 March 2000

7:30 am - 8:30 am CONTINENTAL BREAKFAST

INTRODUCTIONS

8:30 am Welcome. Usha Varanasi -- Northwest Fisheries Science Center.

8:40 am Introduction: context, objectives, agenda, and products. Pamela Mace – Office of Science & Technology

8:45 am NSAWs and other mechanisms for enhancing interactions between the Science Centers and the Office of Science and Technology. Bill Fox – Office of Science & Technology

OVERVIEW PAPER

8:55 am Fisheries management in an ecosystem context: what does this mean, what do we want, and can we do it? Jason Link – NEFSC

SUBTHEME I: ECOSYSTEM PROPERTIES

(e.g., ecosystem "paradigms", ecosystem "health" and integrity, ecosystem services, biodiversity, genetic diversity, ecosystem overfishing, species diversity, size spectra, sustainability criteria and reference points, valuation of alternative ecosystem states, formulating objectives for ecosystem management, management strategies in an ecosystem context – top-down vs bottom-up management)

9:30 am Ecosystem considerations in fisheries management: linking ecosystem management goals with ecosystem research. Pat Livingston – AFSC

9:55 am Ecosystem management - how can we do it? Jon Brodziak and Jason Link – NEFSC

10:20 am - 10:45 am COFFEE BREAK

10:45 am A conceptual basis for fishery resource portfolios. Steve Edwards, Barbara Rountree and Jason Link – NEFSC

11:10 am Incorporating spatial dynamics of fish and fishermen in models of marine protected areas on Georges Bank. Dan Holland – AFSC

11:35 am Measures of overfishing based on MSY. Chuck Fowler – AFSC

12:00 pm Are there ecosystem analogs to overfishing definitions? Steve Murawski – NEFSC

12:25 pm - 1:45 pm LUNCH BREAK: CATERED LUNCH & WORKING LUNCH DEMONSTRATION: ***Demonstration of FACT, the Fisheries Assessment Computational Toolbox.*** Laura Shulman – NEFSC

SUBTHEME II: BIOLOGICAL AND TECHNOLOGICAL INTERACTIONS

(e.g., trophic interactions, multispecies interactions, technological interactions, multispecies models, demonstration and/or critique of ECOPATH, ECOSIM, ECOSPACE, multispecies considerations in rebuilding plans, case studies)

1:45 pm Evaluation of single-species versus multi-species models in the context of managing for maximum sustainable yield. Grant Thompson – AFSC

2:10 pm Importance and impact of predation on the dynamics of Atlantic herring. Bill Overholtz and Jason Link – NEFSC

2:35 pm Trophic cascades and intraguild predation in aquatic food webs. Dvora Hart – NEFSC

3:00 pm Trophic dynamics affect salmon productivity: ecosystem-wide considerations. Robert Emmett and Rick Brodeur – NWFSC

3:25 pm - 3:50 pm COFFEE BREAK

3:50 pm ***Effect of nutrient cycling from carcasses on salmon productivity.*** Robert Bilby – NWFSC

4:15 pm ***The bycatch and mixed species yield-per-recruit of flatfish fisheries on the Eastern Bering Sea shelf.*** Paul Spencer and Tom Wilderbuer – AFSC

4:40 pm ***Associations of species groups from U.S. pelagic longline sets in the region of the Grand Banks with gear characteristics and environmental variables.*** Jean Cramer – SEFSC

5:05 pm ***Use of surficial sediment information and species assemblage analysis for improving trawl survey stratification and abundance estimation.*** Mark Zimmermann – AFSC

5:30 pm - 7:00 pm POSTER SESSION & RECEPTION

POSTERS

The influence of fishing pressure on the spatial distribution and overlap between exploited and unexploited species on Georges Bank. Lance Garrison – NEFSC

Changes in dietary overlap among fish species on Georges Bank during the last three decades: a shift in competitive interactions. Lance Garrison and Jason Link – NEFSC

Multispecies perspectives on the Bering Sea groundfish fishery management regime. Jesus Jurado-Molina and Pat Livingston – AFSC ("Biological and Technological Interactions" theme).

Quantification and dynamics of indicators of ecosystem health, goods, and services: the Georges Bank - Gulf of Maine example. Jason Link – NEFSC

Major Eras in Fisheries Science. Jason Link – NEFSC

Overview of Food Web Dynamics in the Northwest Atlantic: Detecting changes in key processes and parameters in a multispecies context. Jason Link, Frank Almeida, Cheryl Milliken and Lance Garrison – NEFSC

The influence of spatial dynamics on predation mortality of Bering Sea walleye pollock. Pat Livingston, Paul Spencer, Troy Buckley, Angie Greig and Doug Smith – AFSC ("Biological and Technological Interactions" theme).

Marine Mammals: Examples of Sustainability. Charles W. Fowler

Advances in Evaluations of Red Drum Resources in the Gulf of Mexico. Clay Porch – SEFSC

Logbook data from the menhaden purse seine fisheries: improving estimates of catch-at-age and other applications. Joseph W. Smith –SEFSC

A comparison of the accuracy of alternative maximum likelihood length-based stock assessment methods. Erik Williams – SWFSC

Wednesday 29 March 2000

7:30 am - 8:30 am CONTINENTAL BREAKFAST

SUBTHEME III: SHORT AND LONG TERM CLIMATE AND OTHER ENVIRONMENTAL/OCEANOGRAPHIC EFFECTS

(e.g., importance of including climate or other environmental effects, evidence for regime shifts, management strategies under regime shifts, importance for estimation of MSY, case studies)

8:30 am Designing fishery management and stock rebuilding policies for conditions of low frequency climate variability. Alec MacCall – SWFSC

8:55 am Carrying capacity of apex predators and the frequency and cadence of physical forcing in marine food webs. Kerim Aydin – AFSC

9:20 am Tunas and the environment: the ICCAT perspective. Jerry Scott and Steve Turner – SEFSC

9:45 am Analysis of environmental factors on swordfish (Xiphias gladius) catch rates by sex and age from the U.S. longline fleet 1992-1998. Mauricio Ortiz, Jean Cramer, Angelo Bertolino and Jerry Scott – SEFSC

10:10 am - 10:35 am COFFEE BREAK

10:35 am Climate forcing effects on trophically-linked groundfish populations: implications for fisheries management. Jesus Jurado-Molina and Pat Livingston – AFSC

11:00 am Yield versus forage considerations in the regime-dependent Pacific sardine fishery: A comparison of results from management and migration/forage models. Richard Parrish – SWFSC

11:25 am Risk assessment for coho salmon using climate forcing in a life cycle model. Pete Lawson – NWFSC

SUBTHEME IV: SECONDARY EFFECTS OF FISHING

(e.g., effects on habitat, consequences of bycatch, effects on non-target species such as marine mammals, invertebrates and other non-FMP species, case studies)

11:50 am Habitat loss, carrying capacity, and fisheries management. Mike Fogarty – NEFSC

12:15 pm - 1:40 pm LUNCH BREAK (no catered lunch)

1:40 pm Steller sea lion-induced changes in the management of pollock and Atka mackerel fisheries in the North Pacific, 1998-2000. Lowell Fritz – AFSC

2:05 pm Estimates of bycatch by the U.S. Atlantic pelagic longline fleet during 1993-1998. Craig Brown, Jean Cramer and Andy Bertolino – SEFSC

2:30 pm An economic analysis of quota induced discarding. Rita Curtis – Office of Science and Technology

2:55 pm Investigating essential fish habitat for west coast groundfish. Waldo Wakefield and Ian Butler – NWFSC

3:20 pm - 3:45 pm COFFEE BREAK

3:45 pm - 6:00 pm **DISCUSSION GROUPS:**

I. Ecosystem Properties. Facilitated by Bill Overholtz, Jason Link & Steve Murawski

II. Biological and Technological Interactions. Facilitated by Pat Livingston, Alec MacCall, Paul Spencer & Grant Thompson

III. Short and Long-Term Environmental Effects. Facilitated by Anne Hollowed & Rick Methot

IV. Secondary Effects of Fishing. Facilitated by Waldo Wakefield, Mike Fogarty, Ian Butler & Jim Ianelli

6:00 pm ADJOURN

Thursday 30 March 2000

7:30 am - 8:30 am CONTINENTAL BREAKFAST

8:30 am - 10:00 am DISCUSSION GROUPS continue

10:00 am - 10:25 am COFFEE BREAK

10:25 am - 11:30 am DISCUSSION GROUPS wrap-up

OPEN SESSION: ASSESSMENT METHODS

11:30 am MOVEFISH: a spatial algorithm for simulating movement of billfishes. Mark Farber – SEFSC

11:55 am Effects of peak flows on chinook (Oncorhynchus tshawytscha) spawning success in two Puget Sound River Basins. George Pess – NWFSC

12:20 pm - 1:30 pm LUNCH BREAK: CATERED LUNCH & WORKING LUNCH DEMONSTRATION: ***Straying from the Eco path (a critique/demo of the ECOPATH/ECOSIM/ECOSPACE programs).***

Kerim Aydin and Chris Boggs – AFSC & SWFSC

1:30 pm [ECOSIM Application] ***Simulated fishery and trophic impacts of tuna fisheries compared with direct fishery impacts on single species.*** Chris Boggs, Tim Essington – SWFSC, and Jim Kitchell – University of Wisconsin

1:55 pm ***What can spatial and metapopulation components add to a life cycle salmon model in determining risk assessment.*** Norma Jean Sands – NWFSC

2:20 pm ***The Cumulative Risk Initiative - an integrated approach to examining extinction risk and recovery opportunities for Pacific salmon.*** Peter Kareiva, Beth Sanderson, and Michelle McClure – NWFSC

2:45 pm ***Rebuilding plans for an uncertain stock-recruitment relationship, red grouper in the Gulf of Mexico.*** Christopher Legault, Michael Schirripa, and Victor Restrepo – SEFSC & ICCAT

3:10 pm - 3:35 pm COFFEE BREAK

3:35 pm - 5:25 pm DISCUSSION GROUPS REPORT TO PLENARY;
PLENARY DISCUSSES DISCUSSION GROUP RECOMMENDATIONS

5:25 pm WRAP UP

5:30 pm ADJOURN

APPENDIX II: LIST OF PARTICIPANTS

Frank Almeida (NEFSC)
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Robert Bilby (NWFSC)
Chris Boggs (SWFSC)
Jeff Breiwick (AFSC)
Jon Brodziak (NEFSC)
Craig Brown (SEFSC)
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Dean Courtney (AFSC)
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Mark Farber (SEFSC)
Michael Fogarty (NEFSC)
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Mark Zimmermann (AFSC)

AFSC – Alaska Fisheries Science Center
F/HC – Office of Habitat Conservation
F/ST – Office of Science and Technology
MD DNR – MD Department of Natural Resources
NEFSC – Northeast Fisheries Science Center
NWFSC – Northwest Fisheries Science Center
SEFSC – Southeast Fisheries Science Center
SWFSC – Southwest Fisheries Science Center

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